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Department of
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**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-131**

A Classification of Forest Habitat Types of Northern New Mexico and Southern Colorado

Robert L. DeVelice
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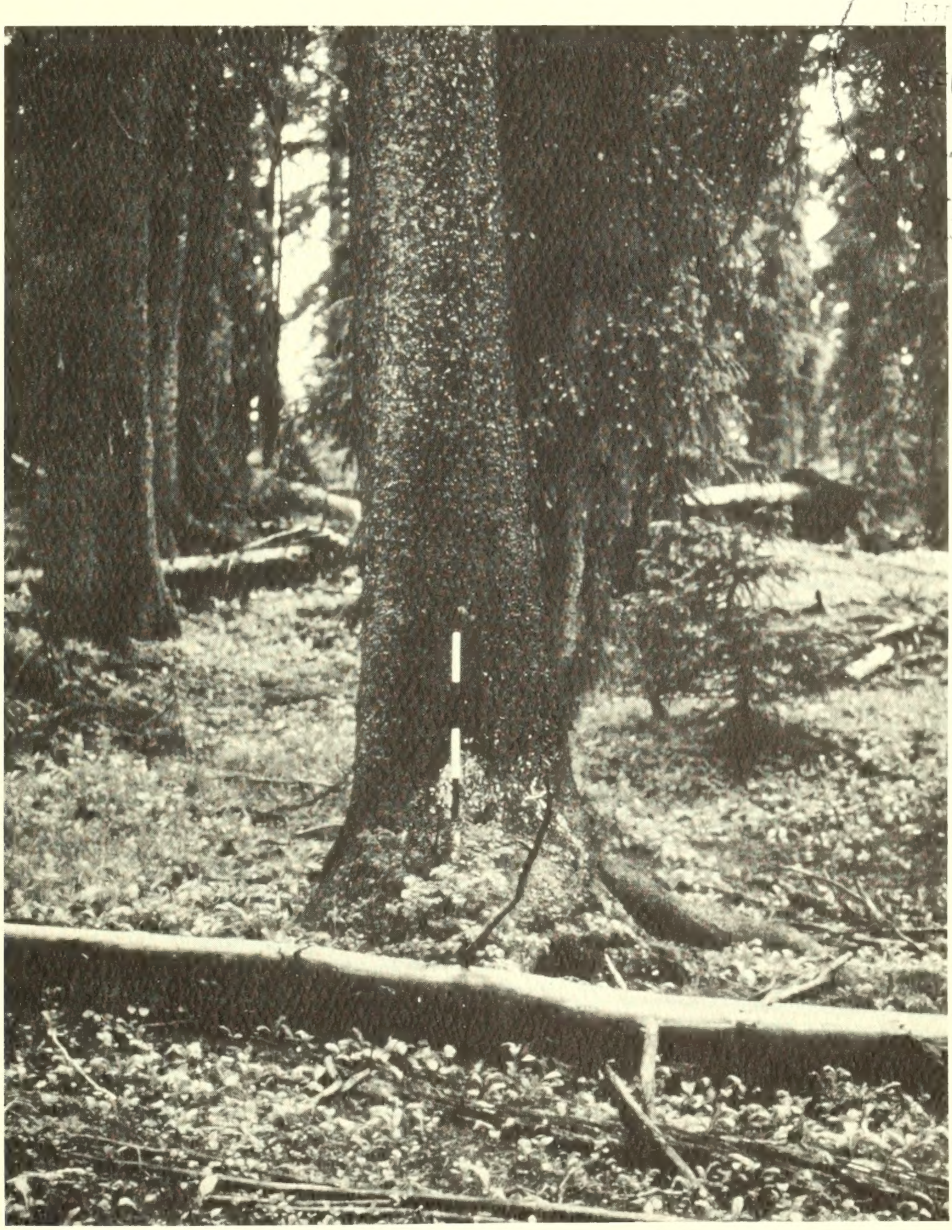

Abstract

Forest habitat types in the mountains of northern New Mexico and southern Colorado were identified and described to develop an ecosystem classfication. The final vegetation classification is based on 618 sample plots. A total of 8 climax series, 44 habitat types, and 12 phases of habitat types are defined. Keys and descriptions for each habitat type are provided. Soils and vegetation relationships, successional trends, management implications, tree productivity from site index, and relationships to other habitat type investigations in the Rocky Mountains are discussed.

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A Classification of Forest Habitat Types of Northern New Mexico and Southern Colorado[1]

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Robert L. DeVelice, John A. Ludwig, William H. Moir, and Frank Ronco, Jr.

MANAGEMENT IMPLICATIONS

Habitat type systems, in conjunction with soils and topographic data, aid in delimiting logical units for management, and improve prediction accuracy for such characteristics as timber and forage production potentials (Layser 1974, Pfister 1976). Additionally, habitat type systems provide an ecological basis for categorizing environmental variation, provide a common system for improving communication among diverse investigators, and aid in improving sampling and experimental design (Pfister et al. 1977). Such usefulness provided the strongest rationale for selecting the habitat type approach for this forestland study in the southern Rocky Mountains.

Classifications of forestlands based on single-factor analyses, such as dominant vegetation, landforms, land uses, or soils, typically are either too general or lack the ecological basis needed for sound multiple-use management (Bailey et al. 1978, Corliss 1974). In contrast, climax vegetation serves as a key to the integrated environment, including climate, soil, and landform conditions as they affect vegetation composition (Daubenmire 1976). Efficient and successful land management is more probable when a classification system is available for dividing the landscape into units of contrasting biotic potentials (Driscoll 1964). The habitat type classification of forests has proven to be very useful to land managers, as evidenced by its general acceptance and utility in those regions where such classifications have been completed and polished (Pfister and Arno 1980).

Classification by habitat type does not imply that managers should manage for climax vegetation. For example, forage production for livestock declines rapidly with advancement of succession towards climax in many western forest habitat types (Pfister[5]); thus, maintenance of seral vegetation may be the goal of management. The usefulness of the climax concept, however, remains unchanged.

INTRODUCTION

Natural vegetation integrates all impinging environmental factors (Daubenmire 1976). Land areas capable of supporting a given plant association at climax are defined as the same habitat type (Daubenmire 1968). Recognition of forest habitat types has proven to be highly useful to land managers (Layser 1974, Pfister 1981). The main advantage of habitat types is that they provide a permanent and ecologically based system of delineating ecosystems (Pfister et al. 1977).

Habitat types are defined on sites with climax or near climax vegetation; thus, they assume stable or near stable climate, soils, and landform. Areas having seral vegetation can be mapped to habitat type by close examination of adjacent plant associations on the same site (Arno 1982), and by using prior studies of plant successional relationships (Pfister et al. 1977).

Forestlands are valuable public resources that provide timber, livestock, wildlife, watershed, and recreation. Effective management of forest resources requires a thorough understanding of how different habitat types respond to different management practices. A given habitat type represents a relatively narrow range of biotic potentials and, thus, a relatively narrow range of management options.

Forest plant association classifications have been developed for 30 areas in the western United States (Pfister 1981). Although this coverage is extensive, large areas still lack habitat type investigations. Prior to this study, little documentation of the forest vegetation of northern New Mexico and southern Colorado had taken place. Moir and Ludwig (1979) described mixed conifer and spruce-fir forests in northern New Mexico but did not sample the extensive ponderosa pine forests. Vegetation studies are generally lacking for the forests of southern Colorado, and those that have been done involved limited sampling areas. Peet (1981) sampled the Spanish Peaks; Dix and Richards (1976) sampled Missionary Ridge in the San Juan Mountains; Shepherd[6] sampled north of Alamosa, Colo.; and Langenheim (1962) sampled in the vicinity of Crested Butte, Colo. (slightly north of our study area).

The objective of this study was the identification and description of forest habitat types in the mountains of northern New Mexico and southern Colorado. The final classification is based primarily on vegetation. However, to produce a better ecological classification, soils and landform were also considered in the identification and description of habitat types.

STUDY AREA

PHYSIOGRAPHY

The study area encompasses the forests of northern New Mexico and southern Colorado. Specifically, they occur in the Spanish Peaks and Wet Mountains of Colorado, and the San Juan and Sangre de Cristo Mountains of both Colorado and New Mexico (fig. 1).

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[5] *Pfister R.D. 1971. Management implications by habitat types. Habitat Type Training Session Manual, 30 p. USDA Forest Service Region 1, May 24-28. Coeur d'Alene, Idaho.*

[6] *Shepherd, Harold R. 1975. Vegetation of two dissimilar bighorn sheep ranges in Colorado. Division Report 4, 223 p. Colorado Division of Wildlife, Denver.*

Most of the data were collected within National Forests; however, a relatively small number of study plots were established on private and public lands outside National Forest boundaries. The sampling area ranged in elevation from about 6,000 to 11,800 feet (1,830 to 3,600 m) and encompassed approximately 10 million acres (4 million ha).

Physiographic provinces in the United States are defined in Thornbury (1965). The three provinces represented in the study area may be described as follows.

Colorado Plateau Province

This province is bounded on the east by the San Juan Mountains uplift. Gently dipping sedimentary rocks characterize most of this province. Relief features are generally the result of incision of canyons into generally flat terrain, rather than upstanding mountain ranges. The Dakota Sandstone, Mesa Verde Sandstone, and Mancos Shale underlie much of the study area within the Colorado Plateau Province.

Forest series studied in the province are predominantly *Pinus ponderosa*. *Abies concolor* is rare in this province, and *Pseudotsuga menziesii* forests form a relatively minor topographic climax in some areas.

Southern Rocky Mountain Province

This province contains the major portion of the study area. Except for the San Juan Mountains in Colorado, the province is composed predominantly of north-south trending ranges of anticlinal structure having igneous and metamorphic rock cores flanked by sedimentary rocks. The ranges included in the portion of the Southern Rocky Mountain Province within the study area are the San Juan, Sangre de Cristo, and Wet Mountains. Secondary ranges are recognized within the extensive San Juan Mountains. These include the La Plata, San Miguel, Needle, and Rico Mountains in Colorado, and the San Pedro, Jemez, and Sierra de Nacimiento Mountains in New Mexico.

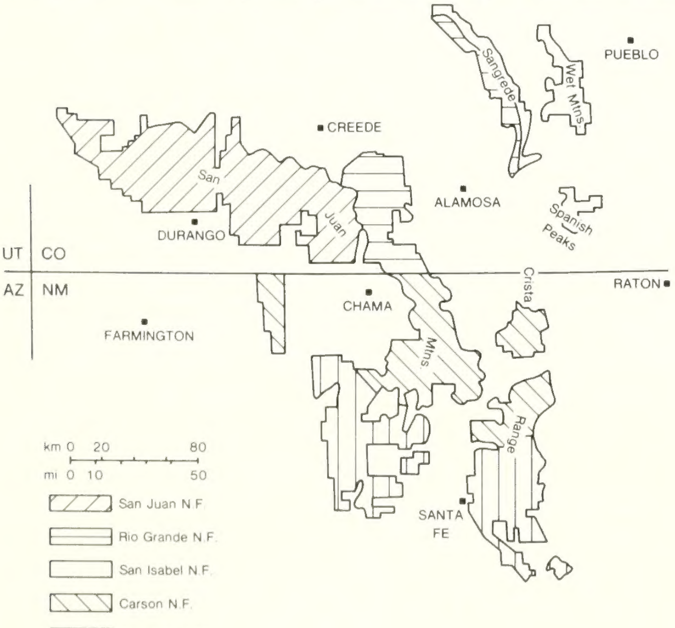

Figure 1.—Location of study area in northern New Mexico and southern Colorado, with National Forest administrative boundaries shown.

The San Juan Mountains were heavily glaciated during the Pleistocene. One late Wisconsin glacier, the Las Animas, was 40 miles (64 km) long, making it perhaps the longest in the Rockies during Pleistocene times. The western flank of the San Juan uplift is bounded by the La Plata, San Miguel, and Rico Mountains.

A dramatic example of volcanic activity is the Valles Caldera in the Jemez Mountains of New Mexico. The caldera measures about 15 miles (24 km) in diameter and was formed by collapse after extrusion of tremendous volumes of tuff.

The Sangre de Cristo Mountains extend from near Salida, Colo., to the vicinity of Santa Fe, N. Mex., a distance of about 140 miles (225 km). Both the Sangre de Cristo and Wet Mountains consist of a core of Precambrian schists, gneisses, pegmatites, and local bodies of granite and diorite, with complexly folded sedimentary rocks occurring in some locations. Extensive Pleistocene glaciation occurred in these mountains.

The Southern Rocky Mountains are the highest in the Rocky Mountain System. Many peaks in excess of 14,000 feet (4,270 m) elevation are found within the province. Because of the great environmental variation in the Southern Rocky Mountain Province, extensive examples of all forest series occur.

Great Plains Province

The Spanish Peaks of Colorado lie within this province. They represent two igneous plugs of granite and granodiorite porphyry. Prominent features of the Spanish Peaks are dikes radiating from the stocks, much like the spokes of a wheel; some of these dikes are 25 miles (40 km) long.

CLIMATE

Mountain climates of the western United States have been described by Baker (1944) and Bradley (1976). The average temperature lapse rate is 5.50° F per 1,000 feet (1.0° C per 100 m) elevation increase. Generally, precipitation increases with elevation in the mountains. Within the study area, an average of 40% of the annual precipitation falls during the period of June through August. The San Juan Mountains of Colorado are the wettest and coldest mountains in the study area largely because of greater snowfall and the absence of chinook winds.

Annual precipitation at 6,500 feet (1,980 m) elevation is approximately 16 inches (410 mm) throughout the study area; however, annual precipitation at about 13,000 feet (3,960 m) ranges from approximately 40 inches (1,020 mm) in the San Juan Mountains in Colorado, to 35 inches (890 mm) in the mountains of northern New Mexico, and to 24 inches (610 mm) in the Sangre de Cristo Range, Wet Mountains, and Spanish Peaks of Colorado. The higher total precipitation at high elevations in northern New Mexico relative to the mountains east of the Continental Divide in southern Colorado probably relates to the rain shadow effect of the massive San Juan Mountains in Colorado. Local conditions may produce much higher precipitation. For example, subalpine rain forests in Colorado have been reported to receive in excess of 100 inches (2,540 mm) of precipitation during the summer (Ives 1942).

Maximum snowfall accumulations vary from 43 feet (13 m) in the San Juans of Colorado, to 26 feet (8 m) in the mountains of south-central Colorado, and to 16 feet (5 m) in the mountains of northern New Mexico.

The number of frost-free days varies from less than 50 days in the *Abies lasiocarpa* series to more than 120 days in the *Pinus ponderosa* series.

Daubenmire (1943) described vegetation zones in the Rocky Mountains and hypothesized the following causes of lower and upper altitudinal limits of species: (1) the upper limit is determined by temperature, (2) the lower limit is determined by low precipitation, and (3) at intermediate elevations exposure and soils are significant in controlling species distribution patterns.

Daubenmire (1943) further proposed that the upper timberline is primarily determined by desiccating winds. In southern Colorado, Bates (1924) observed that total wind for January averaged 13,000 miles (20,920 km) at upper timberline, but was less than 6,000 miles (9,660 km) in the *Picea engelmannii–Abies lasiocarpa* zone just below.

METHODS

FIELD PROCEDURES

Plots were carefully selected for sampling within stands of climax or near climax vegetation following the guidelines of Moir and Ludwig (1983). Forestlands that support, either currently or potentially, any of the following coniferous tree species or their combinations are considered climax or near climax: *Pinus aristata*, *Picea engelmannii*, *Abies lasiocarpa*, *Picea pungens*, *Abies concolor*, *Pinus flexilis*, *Pseudotsuga menziesii*, and *Pinus ponderosa*.

There is considerable disagreement among ecologists regarding the climax or seral status of *Pinus contorta* and *Populus tremuloides* in the Rocky Mountains (Hoffman and Alexander 1980). Supporting the possibility of these species being climax, Moir (1969) recognized a *P. contorta* zone in the Colorado Front Range where *Pseudotsuga menziesii*, *Abies lasiocarpa*, or *Picea engelmannii* had not invaded in 65 to 100 years of pine dominance. Despain (1983) noted climax *P. contorta* communities in Wyoming. Similarly, *P. tremuloides* was observed forming 150-year-old stands in northern Colorado where succession towards *Abies and Picea* was not evident (Hoffman and Alexander 1980). Generally, replacement of *P. tremuloides* requires about 65 years (Ives 1941). *P. contorta* occurs as a minor component of forests in the Sangre de Cristo Range, Spanish Peaks, and Wet Mountains of Colorado. Stands dominated by either of these species were outside the scope of this study.

To minimize the confounding nature of successional vegetation on disturbed sites, areas severely overgrazed, recently logged, herbicide treated, mechanically disturbed, artificially seeded, or irrigated were not sampled. Plots were established within portions of stands that appeared to be relatively uniform in topography and vegetation structure. Efforts were made to locate plots to accurately represent tree and undergrowth vascular plant composition, stocking, and visible site factors of the stand.

The procedures for sampling followed those described by Moir and Ludwig (1983). Both reconnaissance plots and analytical plots were included in the study (Daubenmire and Daubenmire 1968, Franklin et al. 1970, Pfister and Arno 1980, Moir and Ludwig 1983). Analytical plots were used to check and calibrate accuracy of shrub and herb coverage as estimated by the reconnaissance plot method (Pfister and Arno 1980), which is more rapid than the analytical plot method by a factor of two to three. In contrast to coverage measurements taken for shrubs and herbs, tree densities were estimated by numbers of individuals per 2-inch (5-cm) diameter class, providing a better indication of relative reproductive rates among the tree species than coverage (Moir and Ludwig 1983).

A total of 618 plots (375 m^2 per plot) were sampled and each was documented by 35-mm color and/or black and white photographs. In addition, soil profiles observed in soil pits dug in the center of the plots were described for 443 plots. The soils were classified to the subgroup level of soil taxonomy (Soil Survey Staff 1975). Ideally, soil descriptions should be complete enough to classify to family level. Caution is necessary in making generalizations concerning this soils information for four reasons. First, time constraints limited most pit depths to 20 inches (50 cm), instead of the 60 inches (150 cm) generally used when describing southwestern forest soils (Gass et al. 1981). Second, only thickness, structure, texture, color, and coarse fragment content of each horizon were recorded for each pedon. Third, descriptions are based solely on field observations; no samples were collected for laboratory verification of field descriptions. Fourth, our sample of plant associations does not necessarily cover the most widespread soil types. For example, Inceptisols may be overrepresented because they occur on the steep, relatively undisturbed terrain on which many of the plot samples were located. Alfisols typically occur on gently sloping sites that are more disturbed by logging and grazing; thus, they were sampled less in this study.

DATA ANALYSIS

At the end of each field season (summers of 1973, 1980, 1981, and 1982),[7] plant voucher collections were identified and field data refined. Complete plot location data and soil-site data were computer coded in a standard format. These floristic and site data were analyzed using the successive approximation classification strategy outlined by Pfister and Arno (1980) and Moir and Ludwig (1983). Basically, ordination (Pielou 1977) and releve table manipulations (Shimwell 1971) were used to develop a preliminary habitat type classification. Evaluation of the objective results obtained by quantitative analyses was tempered by subjective ecological judgment (Williams 1967).

Site index (100 year base age) of each plot was estimated based on one to three trees of *Picea engelmannii*, *Pseudotsuga menziesii*, or *Pinus ponderosa*, the species depending on the forest series. *P. engelmannii* site index estimates were based on curves developed by Alexander (1967), while *P. menziesii* and *P. ponderosa* site index estimation followed Edminster and Jump (1976) and Minor (1964), respectively.

Timber productivity was rated low, moderate, or high, where low site index = 54 and less, moderate = 55–74, and high = 75 and above. Also, slope steepness was categorized for each habitat type as follows: gentle = 0–10%, moderate = 11–45%, steep = 46–80%, and very steep = in excess of 81%.

Keys and descriptions for each habitat type were written, resulting in this vegetation classification system for the forests of northern New Mexico and southern Colorado.

Soils and vegetation relationships, successional trends, management implications, tree productivity (based on site index), and relationships to other habitat type classifications in the Rocky Mountains were also described for the habitat types. Such descriptions must be considered preliminary since they are based only on data taken in developing this classification. Caution is necessary in relating habitat types described here to those in other areas; composition of entire stands must be considered because the species complement varies geographically (Pfister 1972).

TAXONOMIC CONSIDERATIONS

Nomenclature follows Weber and Johnston (1979). Scientific names of all species in this study and their synonyms are listed in appendix 1.

Certain species were difficult to distinguish in the field, particularly the separation between *Vaccinium scoparium* and *V. myrtillus* because the mature fruits needed to definitively separate these species were rarely available. *V. scoparium* gains dominance over *V. myrtillus* in colder and drier environments (Peet 1981), but the ranges of the two species overlap for the most part. Since *V. scoparium* and *V. myrtillus* are closely similar ecologically (Pfister et al. 1977), all specimens keying to either *V. scoparium* or *V. myrtillus* in this study were grouped under *V. myrtillus*, the more common of the two species. Similarly, the necessary fruits were rarely available for the distinction of *Thermopsis divaricarpa* (*T. pinetorum*) from *T. montana* and *Lathyrus leucantus* from *L. arizonicus*. Thus, these species were grouped under the general headings of *Thermopsis* spp. and *Lathyrus* spp. *Pinus flexilis*, *P. strobiformis*, and their hybrids occur in the study area. Pure *P. flexilis* is characteristic of exposed situations at high elevations, while pure *P. strobiformis* occurs primarily at mid elevations (Layser and Schubert 1979). Because a continuum of variation occurs between these two species, all specimens of this complex were classed as *P. flexilis*.

In northern New Mexico, *Quercus grisea* occurs in addition to *Q. gambelii*. Hybrids between these species have been referred to as *Q. undulata* (Tucker 1961). In this study, those oaks with the most coriaceous subentire leaves are referred to as *Q. undulata*.

Carices were identified using Hermann's (1970) manual. Carices in the section Montanae were generally identified as *Carex rossii* if caespitose or as *C. heliophila* if rhizomatous. Additionally, Harrington (1954) and Weber (1976) were invaluable references for field and herbarium identification of many plants.

DEFINITIONS

Use of climax plant associations—combination of climax tree and undergrowth dominants—as indicators of similar biological potential is termed "habitat typing." "Cover type" and "habitat type" (HT) are not synonyms; cover typing tells something about the current cover but does not consider successional status (Layser and Schubert 1979). In contrast, habitat typing stresses potential climax and, thus, may or may not indicate current cover, but it does communicate something about secondary succession, potential cover, and the environmental conditions (Layser and Schubert 1979).

Associations allow the recognition of more ecologically distinct areas than would be possible if only understory or overstory were considered alone (Daubenmire and Daubenmire 1968), because overstory and undergrowth generally occupy the land independently. The same tree canopy can occur over almost wholly different ground covers. In general terms, one might hypothesize that the tree stratum is more closely tied to macroclimate, whereas the undergrowth is more sensitive to microclimate (Daubenmire and Daubenmire 1968).

Plots were grouped according to the tree species showing the strongest evidence of self-perpetuation—the climax tree species. This is termed the series level of the classification (Hoffman and Alexander 1976). Each series was then subdivided based on the dominant or characteristic undergrowth species, or pair of species in some cases, in the climax community. Thus, habitat type names are two-part. For example, in the habitat type name *Pinus ponderosa/Festuca arizonica*, the first part of the name is the climax tree species and the second part is the climax undergrowth indicator species (Pfister and Arno 1980). In instances where a pair of undergrowth species were used, the two species were separated by a hyphen when of the same life form, or by a slash when of different life forms (e.g., *Abies lasiocarpa/Vaccinium myrtillus-Rubus parviflorus* and *Picea engelmannii/Vaccinium myrtillus/Polemonium pulcherrimum* habitat types, respectively). Further, heterogeneous types were divided into phases, which represent incipient habitat types not at present considered distinct enough for recognition at the habitat type level. Habitat type names were chosen for brevity and for appropriateness in conveying a sense of environmental conditions over a given range. The name does not infer that the only species in the stand are those given in the name. Codominance of two or more tree species at climax and the occurrence of 30 or more understory species is not uncommon.

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[7] *Field data collected by Moir in the summer of 1973 in higher elevation forests (Moir and Ludwig 1979) were combined with the 1980, 1981, and 1982 data for all subsequent analyses.*

Use of climax plant associations to name habitat types does not imply an abundance of climax vegetation in the present landscape (Pfister et al. 1977, Steele et al. 1981). Most current vegetation reflects some form of disturbance and various stages of succession towards climax. Indeed, in areas where timber harvesting and overgrazing have been pervasive, climax vegetation structure is essentially absent. However, habitat types can usually be identified even in seral stands by noting the relative reproductive success of the species present in comparison with known successional trends (Pfister et al. 1977). Stands representing very early successional stages can often be identified to habitat type by comparison with adjacent mature stands having similar topographic and edaphic features (Arno 1982, Pfister et al. 1977).

Plant communities and the soils supporting them are both functional products of the interaction of organisms, climate, geomorphology, parent material, and time (Jenny 1941, Major 1951). Therefore, it should be expected that direct relationships exist between the two complexes (Driscoll 1964). Although correlations between vegetation and soil do not always occur (Daubenmire 1970), they have been reported by many investigators (Anderson 1956, Despain 1973, Driscoll 1964, Spilsbury and Tisdale 1944, Tisdale 1947, Wentworth 1981). Correlations between climates at a "zonal" level, vegetation at a Subseries taxonomic level, and soils at the Subgroup taxonomic level, with modifiers, are major elements of the Terrestrial Ecosystem Survey procedure of the USDA Forest Service, Southwestern Region (Gass 1983).

In a Montana study, Munn et al. (1978) found that range habitat types and soil taxonomic units were related along moisture and soil development gradients. Further, Carleton et al. (1974) found strong relationships between soil moisture and temperature regimes (Soil Survey Staff 1975) and potential natural vegetation in northern New Mexico.

RESULTS AND DISCUSSION

The forest vegetation classification developed for northern New Mexico and southern Colorado defines 44 habitat types and 12 phases in 8 climax forest series (table 1). Keys, and instructions for their use, to identify habitat types are presented in appendix 2.

Nearly all of the classification relates to nonriparian forests with well-developed soil profiles, although some habitat types are described for scree and riparian forests as well. Series descriptions generally follow those of Layser and Schubert (1979) for the Southwest, but are refined for specific application to the northern New Mexico-southern Colorado study area. Generally, habitat types are described in order from cool and moist to warm and dry.

In identifying habitat types in the field, full use should be made of written descriptions in the text and the following material given in the appendixes: plant list (appendix 1), successional status table (appendix 3), tree density and undergrowth cover and constancy tables (appendix 4), and habitat type mozaic diagram (appendix 5). Ideally, identification is best achieved by examining near-pristine vegetation, because the classification was developed from mature, minimally disturbed forest. In practice, however, the classification can be applied to existing forests, and habitat types often can be determined from earlier successional stages. Adjacent habitat types can also aid in identification; however, only the major adjacent habitat types are discussed in this paper.

HABITAT TYPE DESCRIPTIONS

Pinus aristata Series

Pinus aristata/Festuca thurberi habitat type (PIAR/FETH; bristlecone pine/Thurber fescue)

The *Pinus aristata* series is of minor extent in the study area and is represented by only two habitat types: PIAR/FETH and PIAR/FEAR. The PIAR/FETH HT occurs predominately at upper timberline in the San Juan Mountains and Sangre de Cristo Range of Colorado.

Vegetation.—*Picea engelmannii* and *Pinus aristata* typically codominate the overstory. However, in some stands only one of these species may be dominant, the other minor or absent. *Festuca thurberi* is the most conspicuous undergrowth component. Other undergrowth species often present include: shrubs—*Ribes montigenum*; forbs—*Achillea millefolium* ssp. *lanulosa*, *Arnica cordifolia*, *Chamerion angustifolia*, *Oreochrysum parryi*, *Polemonium pulcherrimum* ssp. *delicatum*, *Saxifraga bronchialis*, *Thalictrum fendleri*, and *Trifolium dasyphyllum*.

Physical setting.—This habitat type is generally found on mid and upper slopes at elevations exceeding 10,500 feet (3,200 m), primarily at upper timberline (fig. 2) but sometimes elsewhere in the *Picea engelmannii-Abies lasiocarpa* zone where tree growth is limited by drought. Soils vary from Cryorthents to Cryoborolls. The soils are characteristically skeletal, particularly in those situations where *Pinus aristata* is dominant.

Adjacent habitat types.—The PIAR/FETH HT adjoins *Festuca thurberi* grasslands in drier situations and the PIEN/VAMY/POPU HT on moister sites, such as northerly or less windy exposures.

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Table 1.—List of northern New Mexico-southern Colorado forest habitat types and phases by series.

Series Habitat type name	Abbreviation	Number of plots
Pinus aristata series		
Pinus aristata/Festuca thurberi	PIAR/FETH HT	7
Pinus aristata/Festuca arizonica	PIAR/FEAR HT	4
Picea engelmannii series		
Picea engelmannii/Vaccinium myrtillus/Polemonium pulcherrimum	PIEN/VAMY/POPU HT	
Picea engelmannii phase	PIEN phase	15
Abies lasiocarpa phase	ABLA phase	38
Abies lasiocarpa series		
Abies lasiocarpa/Mertensia ciliata	ABLA/MECI HT	14
Abies lasiocarpa/Moss	ABLA/Moss HT	14
Abies lasiocarpa/Vaccinium myrtillus	ABLA/VAMY HT	62
Abies lasiocarpa/Vaccinium myrtillus-Linneae borealis	ABLA/VAMY-LIBO HT	21
Abies lasiocarpa/Vaccinium myrtillus-Rubus parviflorus	ABLA/VAMY-RUPA HT	7
Abies lasiocarpa/Rubus parviflorus	ABLA/RUPA HT	11
Abies lasiocarpa/Erigeron eximius	ABLA/EREX HT	40
Picea pungens series		
Picea pungens/Linnaea borealis	PIPU/LIBO HT	8
Picea pungens/Erigeron eximius	PIPU/EREX HT	13
Picea pungens/Carex foenea	PIPU/CAFO HT	5
Picea pungens/Arctostaphylos uva-ursi	PIPU/ARUV HT	4
Picea pungens/Festuca arizonica	PIPU/FEAR HT	9
Abies concolor series		
Abies concolor/Vaccinium myrtillus	ABCO/VAMY HT	13
Abies concolor/Erigeron eximius	ABCO/EREX HT	18
Abies concolor/Acer glabrum	ABCO/ACGL HT	22
Abies concolor/phase	ABCO/Sparse HT	26
Abies concolor/Arctostaphylos uva-ursi	ABCO/ARUV HT	7
Abies concolor/Festuca arizonica	ABCO/FEAR HT	10
Abies concolor/Quercus gambelii	ABCO/QUGA HT	13
Pinus flexilis series		
Pinus flexilis/Arctostaphylos uva-ursi	PIFL/ARUV HT	4
Pseudotsuga menziesii series		
Pseudotsuga menziesii/Festuca arizonica	PSME/FEAR HT	7
Pseudotsuga menziesii/Quercus gambelii	PSME/QUGA HT	
Festuca arizonica phase	FEAR phase	12
Quercus gamelii phase	QUGA phase	11
Pinus ponderosa series		
Pinus ponderosa/Arctostaphylos uva-ursi	PIPO/ARUV HT	10
Pinus ponderosa/Festuca arizonica	PIPO/FEAR HT	
Danthonia parryi phase	DAPA phase	7
Festuca arizonica phase	FEAR phase	18
Bouteloua gracilis phase	BOGR phase	8
Pinus ponderosa/Quercus gambelii	PIPO/QUGA HT	
Festuca arizonica phase	FEAR phase	21
Quercus gambelii phase	QUGA phase	26
Pinus edulis phase	PIED phase	14
Pinus ponderosa/Muhlenbergia montana	PIPO/MUMO HT	9
Pinus ponderosa/Bouteloua gracilis	PIPO/BOGR HT	
Schizachyrium scoparium phase	SCSC phase	14
Bouteloua gracilis phase	BOGR phase	18
Pinus ponderosa/Quercus undulata	PIPO/QUUN HT	9
Pinus ponderosa/Artemisia arbuscula	PIPO/ARAR HT	6
Pinus ponderosa/Oryzopsis hymenoides	PIPO/ORHY HT	1
OTHER HABITAT TYPES		
Scree forests		
Pinus aristata/Ribes montigenum	PIAR/RIMO HT	1
Picea engelmannii/Saxifraga bronchialis	PIEN/SABR HT	8
Abies lasiocarpa/Saxifraga bronchialis	ABLA/SABR HT	1
Abies concolor/Holodiscus dumosus	ABCO/HODU HT	4
Pseudotsuga menziesii/Holodiscus dumosus	PSME/HODU HT	4
Pinus ponderosa/Ribes inerme	PIPO/RIIN HT	1
Riparian forests		
Picea engelmannii/Heracleum spondylium	PIEN/HESP HT	3
Picea pungens/Swida sericea	PIPU/SWSE HT	7
Picea pungens/Poa pratensis	PIPU/POPR HT	6
Abies concolor/Galium triflorum	ABCO/GATR HT	4
Pinus ponderosa/Poa pratensis	PIPO/POPR HT	3

Comments.—Stands of this habitat type generally have a parklike appearance, with widely spaced trees or occasionally clusters interspersed with *Festuca* meadows. Because of strong representation of the highly palatable *Festuca thurberi*, the grazing potential of this habitat type is high. However, the generally remote locations of this type make access difficult. This, combined with typically steep slopes, generally in excess of 50%, limits utilization of this habitat type for domestic grazing. Esthetic attributes are probably of greater economic value than the more typically resource-oriented uses that are often a prime consideration in management. Wildlife use, especially as summer range for elk, is an important characteristic of this type. Timber productivity for *Picea engelmannii* is low.

Fires are important within the habitat type but seldom attain high enough intensity in the grass-dominated undergrowth of these open forests to result in devastating crown fires.

Pinus aristata is dominant or codominant in generally drier and more exposed situations. In some locations, *Festuca arizonica*—a typically drier site, lower elevation species than *F. thurberi*—occurs in association with *F. thurberi*.

Unlike situations within other habitat types—PIEN/VAMY/POPU, ABLA/VAMY, or ABLA/Moss—where *Pinus aristata* forms a minor seral component (Moir and Ludwig 1979), the more open forest situations in this type fail to give the more highly shade tolerant *Picea engelmannii* a competitive edge over *Pinus aristata*. Codominance of the two species, or, in some instances, sole occurrence of *P. aristata* is expressed in the PIAR/FETH HT. *Abies lasiocarpa* is a minor component in this rather dry habitat type, supporting Peet's (1981) suggestion that *Picea engelmannii* is more drought-tolerant than *A. lasiocarpa*.

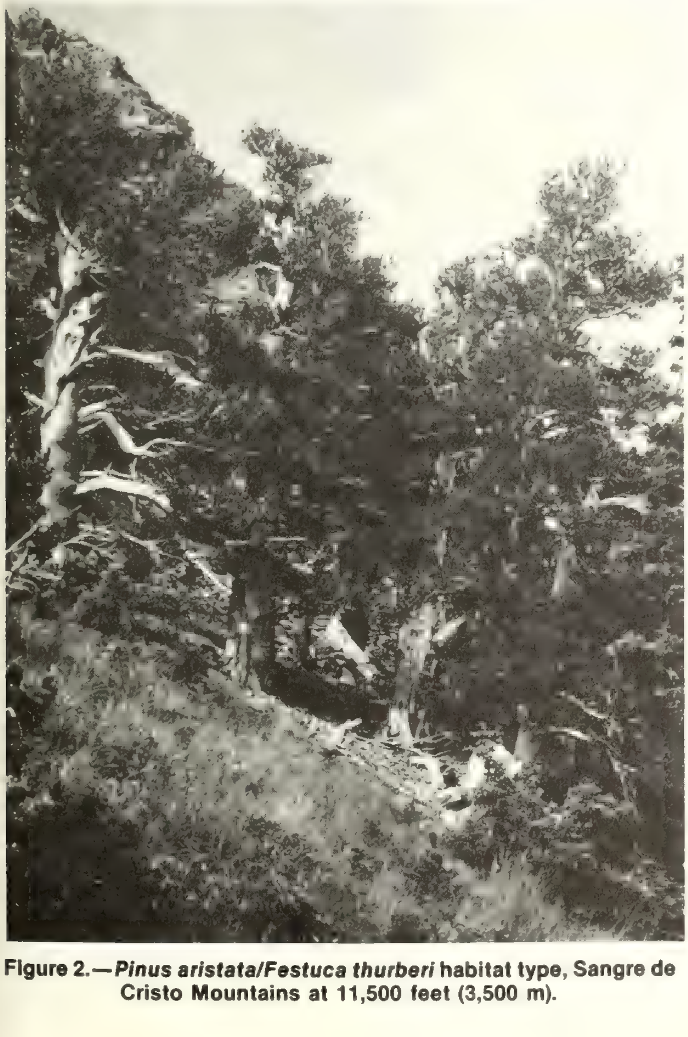

Figure 2.—*Pinus aristata/Festuca thurberi* habitat type, Sangre de Cristo Mountains at 11,500 feet (3,500 m).

Dix and Richards (1976) presented data from a plot on Missionary Ridge in the San Juan Mountains of Colorado that fit the description of the PIAR/FETH HT, although *Pinus aristata* is absent from their plot. Additionally, Shepherd[6] identified a *Picea engelmannii-Festuca ovina-Potentilla fruticosa-Achillea lanulosa* habitat type in the Mosquito Range of central Colorado, and Pfister et al. (1977) described a *Pinus albicaulis* habitat type in Montana, both of which share environmental affinities with this type.

Pinus aristata/Festuca arizonica habitat type (PIAR/FEAR; bristlecone pine/Arizona fescue)

This minor habitat type occurs primarily in the Sangre de Cristo Mountains of New Mexico.

Vegetation.—*Pinus aristata* (fig. 3) dominates or is codominant with *Pseudotsuga menziesii* in the overstory. Grasses dominate the undergrowth, characteristically, *Festuca arizonica*, *Koeleria macrantha*, *Muhlenbergia montana*, and *Poa fendleriana*.

Physical setting.—The PIAR/FEAR HT occurs primarily on steep southerly to westerly upper slopes. Elevations range from 8,600 to 10,000 feet (2,620 to 3,050 m). Soil surfaces typically exhibit rock covers in excess of 15%.

Adjacent habitat types.—Adjoining habitat types include the PIAR/FETH HT at higher elevations and the PSME/FEAR HT at lower elevations.

Comments.—The PIAR/FEAR HT is synonymous with the *Pinus aristata, Festuca arizonica, Muhlenbergia montana, Ribes cerneum* habitat type of Shepherd.[6] To maintain consistency with the two-part nomenclature used throughout this report, the name *Pinus aristata/Festuca arizonica* is used instead of the four-part name of Shepherd.[6]

Picea engelmannii Series

Picea engelmannii/Vaccinium myrtillus/Polemonium pulcherrimum habitat type (PIEN/VAMY/POPU; Engelmann spruce/myrtle blueberry/Jacobs ladder)

The PIEN/VAMY/POPU HT is the only one in the *Picea engelmannii* series. The type is widespread at the highest elevations of northern New Mexico and southern Colorado. It occurs in all mountain ranges exceeding 10,500 feet (3,200 m).

Vegetation.—At the highest elevations, *Picea engelmannii* dominates the overstory, while at slightly lower elevations within the type, both *P. engelmannii* and *Abies lasiocarpa* can be found, the latter often less commonly as mature trees. *Pinus aristata* is sometimes present as a seral tree near the forest-tundra ecotone. The type is above the elevational limits of *Populus tremuloides.*

The undergrowth is characterized by *Vaccinium* spp., ranging in cover from 5% to 95%, and such cold indicator species as *Ligularia amplectens, Luzula parviflora,* and *Polemonium pulcherrimum* ssp. *delicatum* (fig. 4). The presence of *Erigeron eximius* indicates warmer situations within the habitat type.

Two phases are recognized: (1) *Picea engelmannii* (PIEN) phase, in which *P. engelmannii* is climax; and (2) *Abies lasiocarpa* (ABLA) phase, with *A. lasiocarpa* climax or co-climax.

Physical setting.—This habitat type occurs at upper timberline, often in cirques and other cold sites that retain snow cover late into the summer. Elevations range from 9,800 to 11,800 feet (2,990 to 3,600 m), with plots in the PIEN phase generally on sites higher than 11,200 feet (3,410 m) and the ABLA phase generally lower than 11,500 feet (3,500 m). The type occurs on all aspects and on moderate to steep slopes. Soil great groups represented in decreasing order of extent are Cryoboralfs, Cryoborolls, and Cryochrepts.

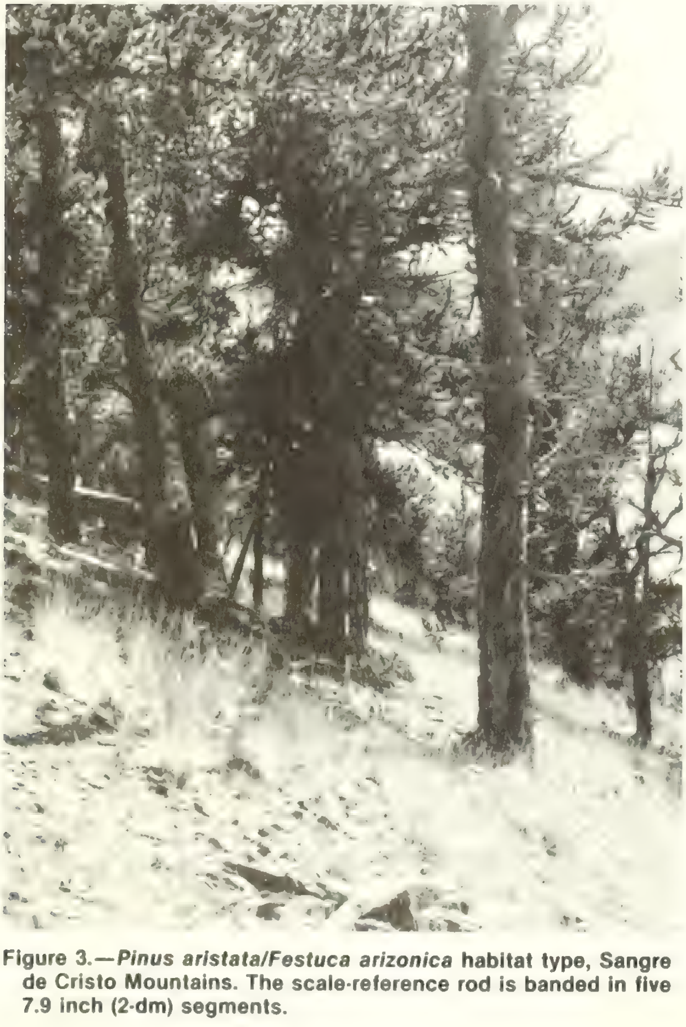

Figure 3.—*Pinus aristata/Festuca arizonica* habitat type, Sangre de Cristo Mountains. The scale-reference rod is banded in five 7.9 inch (2-dm) segments.

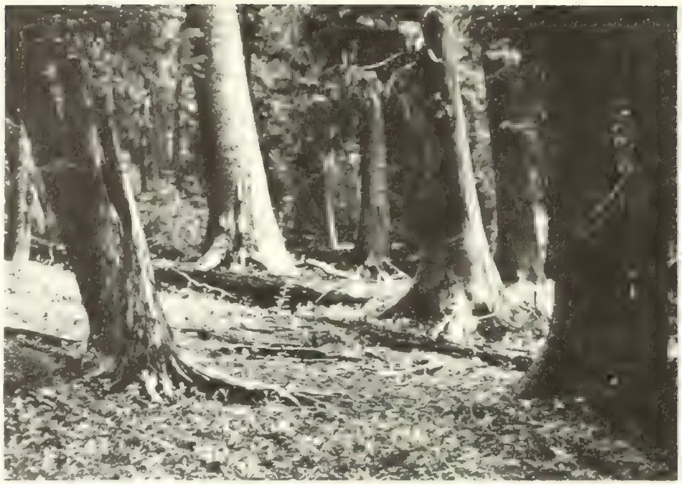

Figure 4.—*Picea engelmannii/Vaccinium myrtillus/Polemonium pulcherrimum* habitat type, *Abies lasiocarpa* phase, San Juan Mountains.

Adjacent habitat types.—While the upper limit of the PIEN/VAMY/POPU HT typically borders alpine tundra, in some instances it adjoins the PIAR/FETH HT. Stands of this type form alternate fingers with those of the very wet ABLA/MECI HT in the San Juan Mountains of Colorado where seeps are common at high elevations. The type often adjoins the ABLA/Moss HT on drier exposures. In almost all locations, the type is bounded at lower elevations by the ABLA/VAMY HT.

Comments.—The habitat type is generally restricted to the coldest extremes of forest growth. Tundra species commonly present include *Acomastylis rossii, Bistorta vivipara, Deschampsia caespitosa, Sibbaldia procumbens,* and *Trifolium dasyphyllum.*

Snowfall and snow accumulation surpass that of all other habitat types in the study area. Dix and Richards (1976) note that *Vaccinium* spp. and *Polemonium pulcherrimum* both increase in frequency with increase in snowpack duration.

If timber is harvested, shading of *Picea engelmannii* regeneration is necessary to prevent insolation damage (Ronco 1970). Under some stand conditions, partial cuttings are likely to result in losses from blowdown (Alexander 1973). The rigorous subalpine environment of this type severely limits timber productivity. Since snow accumulations are typically significant, watershed attributes may be an important consideration for managers. Additionally, esthetic values for recreational pursuits are high.

Moir and Ludwig (1979) first identified the PIEN/VAMY/POPU HT as the *Picea engelmannii/Vaccinium scoparium/Polemonium delicatum* habitat type. The name change reflects the identification problems previously discussed in the case of *Vaccinium*, and the revised taxonomy of Weber and Johnston (1979) in the case of *Polemonium.* Similar types have been reported from the central Rocky Mountains. Peet (1981) described xeric and subalpine *Picea-Abies* forest communities near the tundra-forest ecotone in Rocky Mountain National Park, Colorado. Shepherd[6] reported a *Picea engelmannii-Ribes montigenum-Polemonium delicatum-Bromus* spp. habitat type in the Mosquito Range of central Colorado. High-elevation plots in the *Abies lasiocarpa/Vaccinium scoparium* habitat type in Utah (Pfister 1972) exhibit high contancy of *Polemonium*. Additionally, affinities occur with the *Picea engelmannii-Abies lasiocarpa/Salix glauca* habitat type described in central Colorado (Hess and Wasser[8]). The *Sibbaldia-Bistorta* phase of the *Abies lasiocarpa/Vaccinium scoparium* habitat type in southeastern Wyoming (Wirsing and Alexander 1975) is also similar to the *Polemonium* type described here. In the northern Rocky Mountains, the *Abies lasiocarpa/Luzula hitchcockii* habitat type represents similar environments to those described here (Pfister et al. 1977, Steele et al. 1981).

Abies lasiocarpa Series

This series occurs throughout the highest elevations of the study area, and high similarity exists among habitat types within this series throughout the Rocky Mountains. Forests in this series are extensive and are of considerable economic importance.

Vegetation.—Most overstories exhibit codominance of *Abies lasiocarpa* and *Picea engelmannii*. However, young *Abies* typically outnumber the less shade tolerant *Picea*, suggesting a tendency towards climax dominance by *Abies* (Pfister 1972). *Abies* has a furthur reproductive advantage in that both layering and reproduction by seed can occur, while *Picea* reproduces primarily by seed (Hoffman and Alexander 1976). *Picea* is the more long-lived of the two species, however, so few pure *Abies* stands occur.

Following major disturbance, *Populus tremuloides* is a major seral species at the lower elevations of the series. In rare instances, *Pinus contorta* replaces *Populus tremuloides* as the seral component. Lower elevations in this series also support *Abies concolor* and *Pseudotsuga menziesii* as seral or minor climax components. Sites at upper elevations undergo direct successions to *Picea engelmannii* and *Abies lasiocarpa*.

Undergrowths are highly varied. Maximal mesic conditions are reached within this series, in the ABLA/MECI HT. Within the wet forests, species lists commonly exceed 50 taxa in a given plot. Very cold conditions also are prevalant within this series, particularly in the ABLA/VAMY HT.

Vaccinium spp. are the most characteristic undergrowth plants of most communities in the *Abies lasiocarpa* series. Havas (1971) suggests the distribution of *Vaccinium* spp. is affected by the accumulation and persistence of snow, which prevents dessication. The occurrence of *Vaccinium* spp. thus suggests cold, snowy environments characteristic of the *A. lasiocarpa* series.

Physical setting.—At the highest elevations in the series (11,800 feet or 3,600 m), environments include cirques and other cold sites that retain snow cover late into summer, while lower elevations (8,850 feet or 2,700 m) are relatively warm. All landform types occur within the series, ranging from dry-exposed ridges (ABLA/Moss HT) to wet-sheltered seep slopes (ABLA/MECI HT). Soils are all in cryic great groups (Carleton et al. 1974).

Adjacent habitat types.—At its upper limit, the *Abies lasiocarpa* series borders either the *Picea engelmannii* series or alpine tundra. At its lower limit, the series adjoins the *Picea pungens* series and herb-rich habitat types in the *Abies concolor* series on moist sites, and herb-sparse *Abies concolor* habitat types on dry sites.

Comments.—Timber productivity is generally limited by the rigorous subalpine environment. Lower elevation sites have the highest timber potentials. Timber management at low elevations may favor either *Picea engelmannii* or *Pseudotsuga menziesii*. However, caution is necessary when managing for *P. menziesii* because frost damage to regeneration may be severe. Wet habitats within the series require special care during timber harvests to prevent severe soil compaction, erosion, raising of the water table, and conversion to sedge communities.

Heavy snow accumulations within the series indicate that the sites have a high potential for water production. Also, the esthetics of forests in the *Abies lasiocarpa* series make them valuable for recreation. Because the rate of recovery following major disturbance is slow (Pfister 1976), heavy timber harvests could affect recreational use for long periods.

Domestic forage production is generally poor except in localized valley bottom sites. Big game species utilize forests and adjacent nonforested communities as summer range.

Fire has played a major role in the ecology of portions of this series, as evidenced by extensive *Populus tremuloides* stands. The large areas of such seral communities, often perpetuated by a scant conifer seed source, are visual evidence of alteration by fire that can persist for decades or even centuries (Steele et al. 1981). Snow avalanches often occur at upper elevations, and result in mosaics of varying stages of forest development.

Abies lasiocarpa/Mertensia ciliata habitat type (ABLA/MECI; subalpine fir/tall mertensia)

This habitat type is restricted to wet seep slopes high in the San Juan and Sangre de Cristo Mountains.

Vegetation.—*Picea engelmannii* and *Abies lasiocarpa* codominate the overstory. The most conspicuous feature of the vegetation in this type is not the overstory but the undergrowth (fig. 5). Total herb cover in excess of 100% is common. Often five or more species will be abundantly represented in the undergrowth. Species lists commonly exceed 50 taxa within a given plot. Thus, richness and luxuriant herbaceous growth characterize this type. The undergrowth is patchy, reflecting variations in soil moisture.

Dominant wet-site species having a high fidelity for this type include: *Carex bella* and other wet-site carices; and such forbs as *Caltha leptosepala, Cardamine cordifolia, Erigeron coulteri, Geranium richardsonii, Ligusticum porteri, Mertensia ciliata, Mitella pentandra, Oxypolis*

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[8] Hess, Karl, and C. H. Wasser. 1982. Habitat type classification of a part of the White River-Arapaho National Forest. Draft Report, 190 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

fendleri, Saxifraga odontoloma, Senecio triangularis, and *Streptopus amplexifolius.* Dry hummocks, such as around tree bases, support *Vaccinium* spp. and *Polemonium pulcherrimum* ssp. *delicatum.*

Physical setting.—Slopes are typically gentle to moderate and aspects are generally northerly. Elevations vary from 9,200 to 11,200 feet (2,800 to 3,410 m). Topographic positions on which this type occur typically are lower and mid slopes. Soils are characteristically deep and exhibit high water tables. Soil subgroups include Aquic Cryoboralfs, Argiaquic Cryoborolls, Argic Pachic Cryoborolls, and Aquic Cryofluvents.

Adjacent habitat types.—Commonly, where seeps emerge in areas dominated by the PIEN/VAMY/POPU HT, the ABLA/MECI HT occupies the seep areas. Wet meadows dominated by *Carex* spp. and *Juncus* spp. adjoin the type in some areas.

Comments.—This habitat type represents the wettest nonriparian conditions of the southern Rocky Mountains, resulting in long intervals between fires. The typically sheltered topographic position reduces the occurrence of extensive windthrow. Thus, many forests of this type exhibit climax conditions (Peet 1981).

Typically, seep areas are a minor component of the landscape, and habitat types associated with them would likely have little importance in management. However, some high-elevation areas have extensive seep slopes where the fragile aquic soils make conventional silvicultural operations difficult. Skidding of logs can compact the soil and accelerate erosion. Use of heavy equipment can be particularly damaging in the spring and early summer when water tables are highest. Furthermore, clearcutting often results in the formation of dense *Carex* communities that are unsuitable for conifer establishment without considerable site preparation. Steele et al. (1981) suggest that removal of the overstory may raise the water table, severely hindering regeneration.

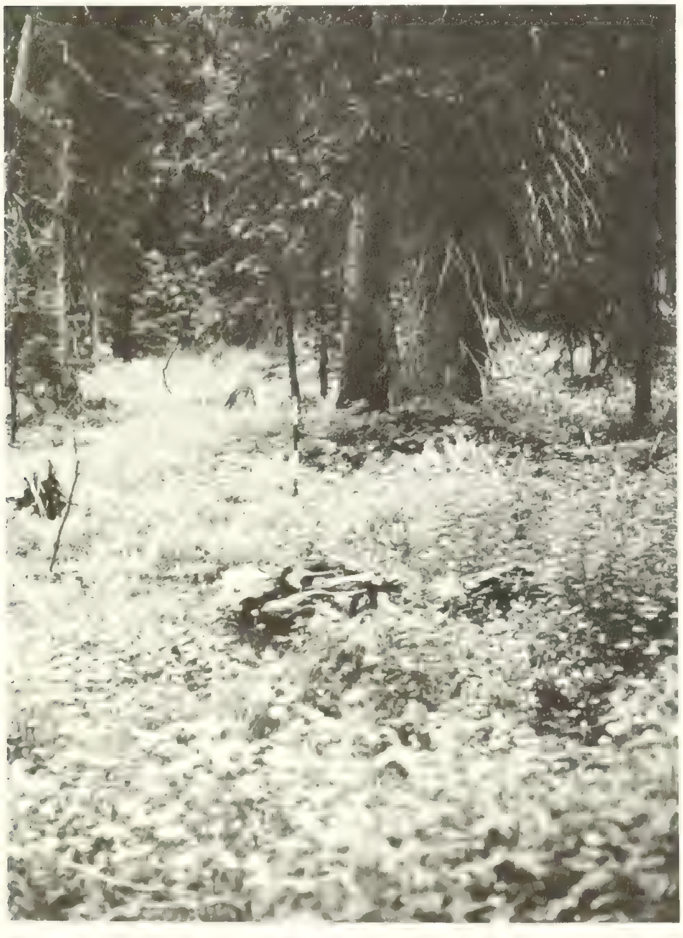

Figure 5.—*Abies lasiocarpa/Mertensia ciliata* habitat type, San Juan Mountains.

The abundant forage and proximity to streams attract livestock; as a result, compaction of the wet soil and loss of plant cover may be severe. Wildlife use also may be high because abundant food and cover are present for elk, deer, and black bear; also, wet spots are available for elk and bear to wallow. This habitat type is an important water producer.

Dix and Richards (1976) presented data from two plots near Wolf Creek Pass in the San Juan Mountains of Colorado that may be classified as the ABLA/MECI HT. The type is approximately synonymous with the *Abies lasiocarpa/Senecio triangularis* habitat type described in Idaho by Steele et al. (1981). Peet (1981) described a wet *Picea-Abies* forest community in northern Colorado that is equivalent to the ABLA/MECI HT. Steele et al. (1981) and Pfister et al. (1977) described an *Abies lasiocarpa/Calamagrostis canadensis* habitat type that has affinities to the type described here. In addition, Steele et al. (1981) reported closely related *Abies lasiocarpa/Streptopus amplexifolius* and *Abies lasiocarpa/Caltha biflora* habitat types.

Abies lasiocarpa/Moss habitat type (ABLA/Moss; subalpine fir/moss)

This habitat type is restricted primarily to the Sangre de Cristo, San Pedro, and Jemez Mountains of northern New Mexico.

Vegetation.—*Picea engelmannii* and *Abies lasiocarpa* typically codominate the overstory, and *Populus tremuloides*, or occasionally *Pinus aristata*, are minor seral trees. At lower elevations in this habitat type, elements of the mixed conifer zone appear, as evidenced by a *Pseudotsuga menziesii* seral component and the presence of *Acer glabrum.* Vascular plants are minor in the undergrowth of this comparatively dry habitat type (fig. 6). *A. glabrum, Juniperus communis,* or *Vaccinium* spp. occasionally attain 10% cover. *Vaccinium caspitosum* was found to be an important diagonostic species in northern New Mexico (Moir and Ludwig 1979); however, moss cover is the only prominent feature of the undergrowth. The sparseness of the undergrowth in this type relates to the generally severe character of the sites.

Physical setting.—Elevations range from 9,800 to 11,500 feet (2,990 to 3,500 m) and slopes vary from gentle to steep. Generally, the type occurs on ridges or upper slopes on any aspect.

Adjacent habitat types.—The ABLA/Moss HT lies within the elevational range of the PIEN/VAMY/POPU and the ABLA/VAMY HT's and adjoins them in less exposed situations.

Comments.—The ABLA/Moss HT was first described as the *Picea engelmannii*/Moss habitat type by Moir and Ludwig (1979). Because *Abies lasiocarpa* is generally codominant with *P. engelmannii* in stands of this habitat type in northern New Mexico and southern Colorado, the type is here placed in the *A. lasiocarpa* series. Related vegetation includes the *Picea engelmannii, Pinus aristata, Trifolium dasyphyllum, Poa* habitat type (Shepherd[6]) and the *Pinus contorta* forest community of central Colorado (Peet 1981). Affinities also exist with the *Abies lasiocarpa/Juniperus communis* and the *Picea engelmannii/Hypnum revolutum* habitat types described in central Idaho (Steele et al. 1981). Dix and Richards (1976) provided data from one stand on Missionary Ridge in the San Juan Mountains of Colorado that is identifiable as the ABLA/Moss HT.

Timber productivity is low within this type and management alternatives are limited. Livestock find little forage and seldom use this habitat type, although it does provide cover for elk and deer that feed in adjacent habitat types.

Abies lasiocarpa/Vaccinium myrtillus habitat type (ABLA/VAMY; subalpine fir/myrtle blueberry)

This is one of the most widespread habitat types, not only in the southern Rockies, but throughout the high elevations of the Rocky Mountain system (Hoffman and Alexander 1980). The type is most poorly represented in that part of the Rockies where the oceanic climatic influence is strongest, for example, in eastern Washington and northern Idaho (Daubenmire and Daubenmire 1968). The ABLA/VAMY HT occurs in all high mountains of northern New Mexico and southern Colorado. Its major importance in the study area is indicated by the fact that it is represented by 62 of the 234 *Picea engelmannii-Abies lasiocarpa* plots sampled.

Vegetation.—*Picea engelmannii* and *Abies lasiocarpa* codominate the climax overstory; few stands exhibit *Picea* dominance over *Abies. Pseudotsuga menziesii* and *Populus tremuloides* occur as seral trees in some stands. *Pinus contorta* is considered a major seral species in this type in most other areas in the Rockies (Daubenmire and Daubenmire 1968; Hess and Wasser;[8] Hoffman and Alexander 1976, 1980; Peet 1981; Pfister 1972; Pfister et al. 1977; Steele et al. 1981; Wirsing and Alexander 1975). In contrast, *P. contorta* was not found in any plots of this habitat type within the study area, even though it reaches its southernmost range in southern Colorado.

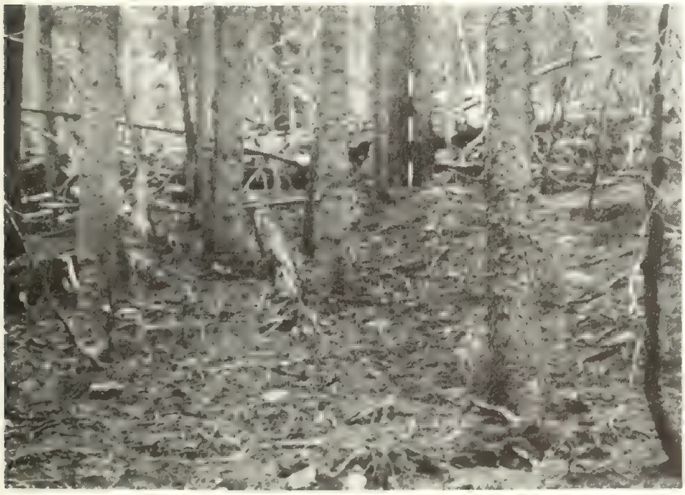

Figure 6.—*Abies lasiocarpa*/Moss habitat type. The sparse undergrowth is characteristic of this type.

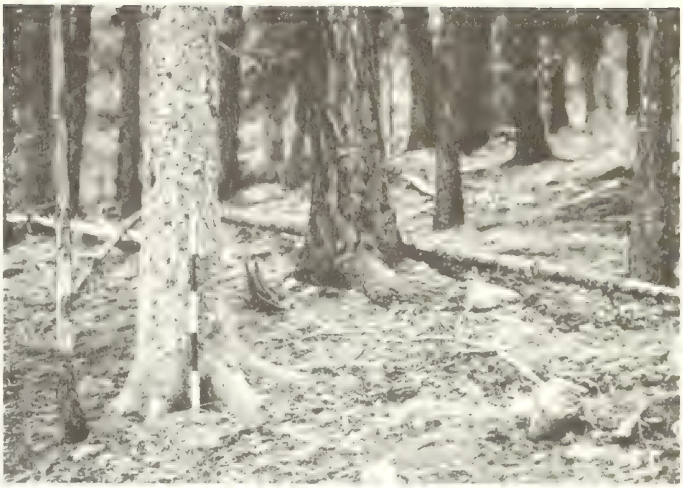

Figure 7.—*Abies lasiocarpa/Vaccinium myrtillus* habitat type, San Juan Mountains.

Vaccinium spp. dominate the undergrowth, but species diversity is typically low in drier portions of the habitat type. In moister situations, herbaceous species may attain high diversity and total coverage in excess of 30%. Dominant shrubs include *Acer glabrum, Lonicera involucrata, Mahonia repens, Orthilia secunda, Pachistima myrsinites, Ribes montigenum, Vaccinium scoparium*, and *V. myrtillus*. Common herbs are *Arnica cordifolia, Artemisia franseriodes, Bromopsis ciliata, Fragaria ovalis, Geranium richardsonii, Lathyrus* spp., *Oreochrysum parryi, Pedicularis racemosa*, and *Thalictrum. Erigeron eximius* is important in moist, warm sites and *Mertensia ciliata* in wet microsites throughout the type. High cover of *Vaccinium* spp. relative to other species is diagnostic for this type (fig. 7).

Physical setting.—Elevations range from 8,900 to 11,200 feet (2,710 to 3,410 m). The type occurs on all aspects and on moderate to steep slopes. Many south-facing slopes in this habitat type are burned-over and characterized by *Populus tremuloides* or other seral species (Moir and Ludwig 1979). Soil great groups represented include Cryoboralfs, Cryoborolls, Cryochrepts, and Cryorthents.

Adjacent habitat types.—This type adjoins the ABLA/Moss HT on drier exposures. The ABLA/VAMY-RUPA, ABLA/VAMY-LIBO, or the ABLA/EREX HT's commonly form the low-elevation ecotone with this type, while upper elevations support the PIEN/VAMY/POPU HT.

Comments.—In contrast to the PIEN/VAMY/POPU HT, tundra plants are generally absent and snowfall usually is not retained as long (Dix and Richards 1976). Also, in contrast to the PIEN/VAMY/POPU HT, *Populus tremuloides* is a major seral species. Undergrowths are herb-rich beneath early-successional *Populus* canopies (Moir and Ludwig 1979). Dominant herbs can include *Bromopsis ciliata, Geranium richardsonii, Lathyrus* spp., *Thalictrum fendleri*, and *Thermopsis* spp.

This type, or the closely related *Abies lasiocarpa/Vaccinium scoparium* habitat type, has been described in the southern Rockies (Fitzhugh et al.[9]), in the central Rockies (Hess and Wasser;[8] Hoffman and Alexander 1976, 1980; Peet 1981; Pfister 1972; Wirsing and Alexander 1975), and in the northern Rockies (Daubenmire and Daubenmire 1968, Pfister et al. 1977, Steele et al. 1981). The environment and floristics of the ABLA/VAMY HT appear to be the same as that described in the literature for the *Abies lasiocarpa/Vaccinium scoparium* habitat type. Even where *Vaccinium myrtillus* is the only dominant *Vaccinium*, the environment of these cold, snowy forests is the same as the *V. scoparium* dominated areas in the central and northern Rocky Mountains. Both *V. myrtillus* and *V. scoparium* occur in many plant communities in the ABLA/VAMY HT; however, *V. myrtillus* was chosen in naming the habitat type as it is the more common of the two species in northern New Mexico and southern Colorado. The type is synonymous with the *Abies lasiocarpa/Vaccinium scoparium* habitat type described by Moir and Ludwig (1979).

The relationship between the ABLA/VAMY and the ABLA/EREX HT's is close. Shifts from a *Vaccinium*-dominated to an herb-dominated undergrowth probably reflect a gradient of increasing temperature (Moir and Ludwig 1979).

Timber productivity is low to moderate. *Abies* reproduction is generally heavier than *Picea* under tree canopies. Cutting will favor *Abies lasiocarpa* in the replacement stand (Hoffman and Alexander 1976). Wet variants of this type—as indicated by herb-rich conditions—appear to be converted to sedge fields following clearcutting, presenting severe regeneration problems. Drier areas exhibit slow changes in undergrowth vegetation following cutting, and competition is not severe between tree seedlings and the undergrowth (Hoffman and Alexander 1980).

The ABLA/VAMY HT characteristically provides poor grazing for livestock because of the short growing season, limited numbers of forage species, and low productivity resulting from shade associated with the generally continuous tree canopy (Steele et al. 1981). However, it does provide valuable summer range for big game. Summer recreational use may be high.

As with other high-elevation habitat types, one of the most important management considerations is the watershed value associated with the widespread and characteristically deep snowpack received by the habitat type (Leaf 1975).

Abies lasiocarpa/Vaccinium myrtillus-Linnaea borealis habitat type (ABLA/VAMY-LIBO; subalpine fir/ myrtle blueberry-twinflower)

This habitat type is geographically widespread but topographically restricted. The type is most common in the San Juan Mountains of Colorado and in the Sangre de Cristo Range of Colorado and New Mexico.

Vegetation.—The ABLA/VAMY-LIBO HT is found at the ecotone of *Picea engelmannii-Abies lasiocarpa* and mixed conifer forests and, thus, supports many species common to both cover types. *Abies concolor, Pseudotsuga menziesii*, and *Populus tremuloides* are important seral trees. In Colorado, *Pinus contorta* sometimes occurs in seral stands. The wealth of tree species increases the difficulty of describing forest development following disturbance (Peet 1981). Typically, shrubs and forbs are abundant in the undergrowth, with *Vaccinium* spp. and *Linnaea borealis* the dominant indicators. In drier situations, however, *Rubus parviflorus* is dominant over *Linnaea borealis*. *Arnica cordifolia, Artemesia franseriodes, Erigeron eximius, Fragaria ovalis, Lathyrus* spp., *Oreochrysum parryi, Pachistima myrsinites*, and *Viola canadensis* often exhibit high coverage. Abundant moss cover indicates the moist conditions of this type (fig. 8).

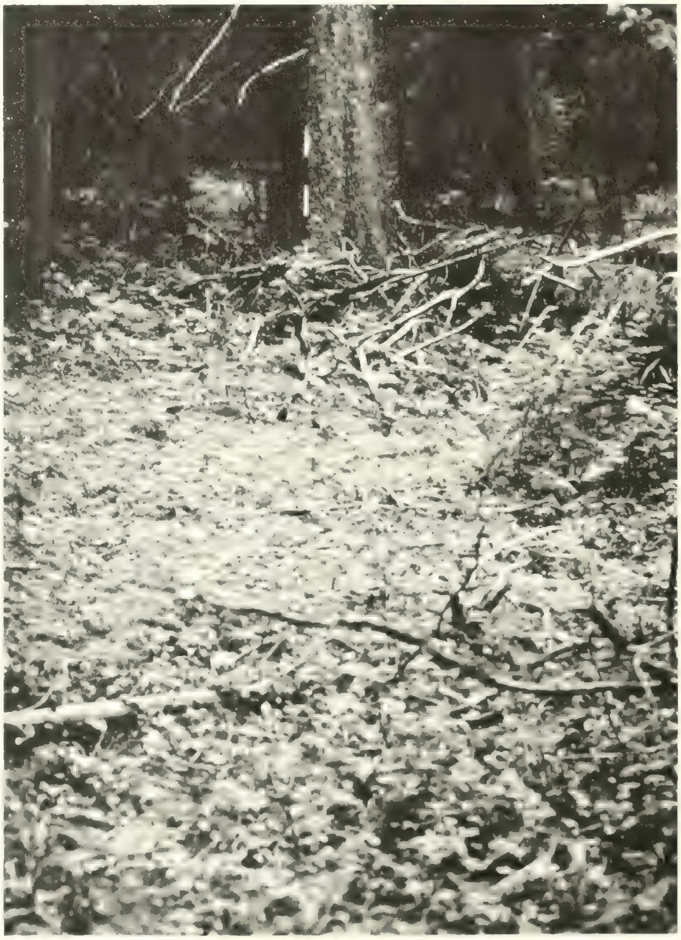

Figure 8.—*Abies lasiocarpa/Vaccinium myrtillus-Linnaea borealis* habitat type, San Juan Mountains, at 8,950 feet (2,730 m).

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[9] *Fitzhugh, E. Lee, William H. Moir, John A. Ludwig, and Frank Ronco, Jr. A classification of forest habitat types of the Apache, Gila, and Magdalena District, Cibola National Forests, Arizona and New Mexico. Manuscript in preparation. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.*

Physical setting.—The habitat type occurs predominately on north- and northeast-facing mid and lower slopes in the *Abies lasiocarpa* series at elevations ranging from 8,700 to 9,800 feet (2,650 to 2,990 m). Soils include Cryoborolls, Cryoboralfs, and Cryorthents.

Adjacent habitat types.—The ABLA/VAMY-LIBO type shows affinities to both the ABLA/EREX and the ABLA/VAMY HT's, and adjoins them on warmer and colder sites, respectively. Lower elevations of similar topography may support the PIPU/LIBO HT.

Comments.—Moir and Ludwig (1979) described the *Abies lasiocarpa/Vaccinium myrtillus-Linnaea borealis* habitat type as the *Abies lasiocarpa/ Vaccinium scoparium/Linnaea borealis* habitat type. The name change from *Vaccinium scoparium* to *V. myrtillus* reflects the identification problems discussed earlier. The type is similar to the *Abies lasiocarpa/Linnaea borealis* habitat type in Montana (Pfister et al. 1977) and in Idaho (Steele et al. 1981), which also have a strong complement of *Vaccinium*. The *Picea engelmannii-Abies lasiocarpa/Pachistima myrsinites* habitat type (Hess and Wasser[8]) and the mixed mesic forest community (Peet 1981) of central Colorado are also similar to the ABLA/VAMY-LIBO HT described here.

Timber productivity is moderate. Either *Picea engelmannii* or *Pseudotsuga menziesii* may be considered for timber management. When the type is being managed for *Pseudotsuga*, frost damage may be severe (Pfister et al. 1977).

Although grass production is limited, the value for domestic grazing of forbs may be moderate. Diverse shrub and forb layers typically provide good big game browse. *Vaccinium* fruits may be important feed for grouse and black bear. Water yield is quite high.

Abies lasiocarpa/Vaccinium myrtillus-Rubus parviflorus habitat type (ABLA/VAMY-RUPA; subalpine fir/myrtle blueberry-thimbleberry)

This habitat type occurs in cool, moist, lower elevations within the *Abies lasiocarpa* forests of Colorado's San Juan Mountains.

Vegetation.—*Abies lasiocarpa* and *Picea engelmannii* codominate the climax overstory. *Pseudotsuga menziesii* and *Populus tremuloides* are the most important seral trees. Undergrowths are diverse and total canopy cover commonly exceeds 100%. Dominant shrubs include *Lonicera involucrata, Pachistima myrsinites, Rubus parviflorus*, and *Vaccinium* spp. (fig. 9). Characteristic herbs are *Arnica cordifolia, Bromopsis ciliata, Erigeron eximius, Geranium richardsonii, Oreochrysum parryi*, and *Smilacina racemosa*.

Physical setting.—The habitat type most commonly occurs on relatively moist, steep, northerly, lower slopes in the 8,800 to 9,700 foot (2,680 to 2,960 m) elevation range. Soils are primarily Typic Cryoboralfs.

Adjacent habitat types.—The ABLA/VAMY-RUPA HT adjoins at higher elevations, while the ABLA/RUPA HT or cool-moist mixed conifer habitat types are encountered at lower elevations.

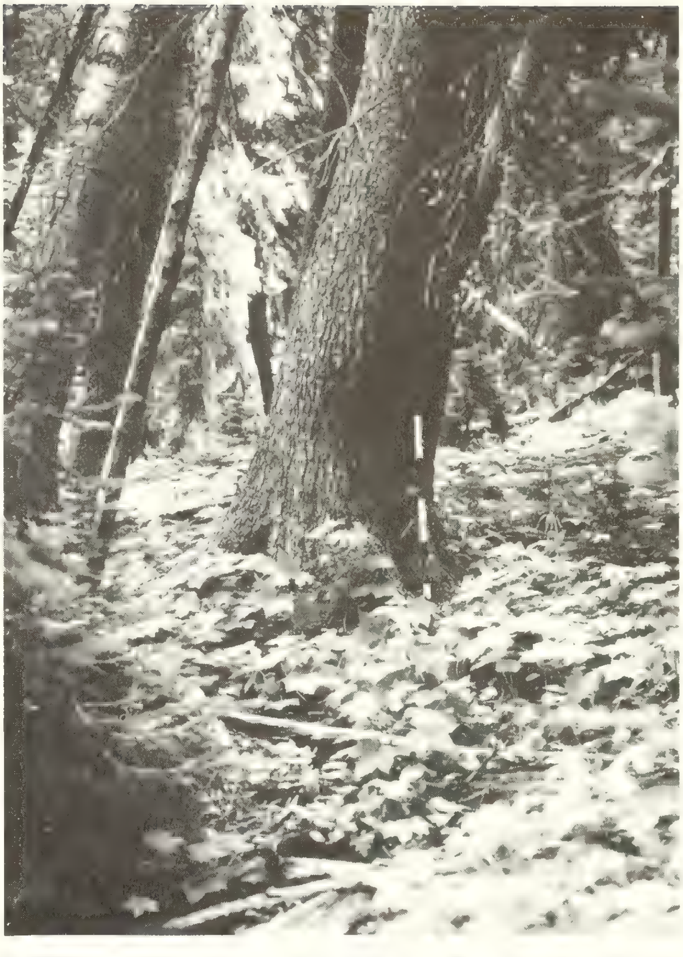

Figure 9.—*Abies lasiocarpa/Vaccinium myrtillus-Rubus parviflorus* habitat type, San Juan Mountains. It features shrub- and herb-rich undergrowths.

Comments.—The ABLA/VAMY-RUPA HT is closely related to the warmer ABLA/RUPA HT described in this report and in southwestern New Mexico by Fitzhugh et al.[9] and Moir and Ludwig (1979). The type is characteristic of those forests in the southwestern United States receiving the highest growing season precipitation (Moir and Ludwig 1979).

Abies lasiocarpa/Rubus parviflorus habitat type (ABLA/RUPA; subalpine fir/thimbleberry)

This habitat type is restricted to relatively moist portions of Colorado's San Juan Mountains.

Vegetation.—Both *Abies lasiocarpa* and *Picea engelmannii* dominate the climax overstory. *Pseudotsuga menziesii* and *Populus tremuloides* are major seral species.

Undergrowths are rich in species diversity, which is suggestive of mesic conditions, and are similar in appearance to those of the ABLA/VAMY-RUPA HT, except that *Vaccinium* spp. are lacking. Dominant shrubs include *Acer glabrum, Lonicera involucrata, Pachistima myrsinites*, and *Rubus parviflorus*. Common herbs are *Arnica cordifolia, Artemisia franseriodes, Erigeron eximius, Geranium richardsonii, Lathyrus* spp., *Ligusticum porteri, Smilacina stellata*, and *Thalictrum fendleri*.

Physical setting.—The ABLA/RUPA HT most commonly occurs on steep, northerly, lower slopes in the 8,900 to 9,800 foot (2,710 to 2,990 m) elevation range. Soils are predominantly Typic Cryoboralfs and Argic Cryoborolls.

Adjacent habitat types.—At lower elevations, this habitat type commonly adjoins the ABCO/ACGL HT. The common ecotones at higher elevations are with either the ABLA/VAMY or the ABLA/VAMY-LIBO HT's. The ABLA/EREX HT occurs on rather similar wet locations.

Comments.—The ABLA/RUPA HT is characteristically moist. It has been previously described in the Mogollon Mountains of southern New Mexico by Moir and Ludwig (1979) and Fitzhugh et al.[9] Both the San Juan and Mogollon Mountains receive high precipitation, which may explain the occurrence of *Rubus parviflorus* in both areas.

Slopes are generally too steep to be harvested by conventional logging techniques or grazed by domestic stock. Water yield and big game utilization are generally high.

Abies lasiocarpa/Erigeron eximius habitat type (ABLA/EREX; subalpine fir/forest fleabane)

This habitat type is widespread throughout the mountains of southern Colorado and northern New Mexico.

Vegetation.—*Pseudotsuga menziesii, Populus tremuloides,* and *Abies concolor* generally occur as seral trees within this type. When *Vaccinium* spp. are present, they are minor relative to *Erigeron eximius* (fig. 10). Species that often typify the characteristically shrub- and herb-rich undergrowth include: shrubs—*Lonicera involucrata, Pachistima myrsinites,* and *Ribes montigenum*; grasses—*Bromopsis ciliata*; and forbs—*Arnica cordifolia, Fragaria ovalis, Geranium richardsonii, Mertensia ciliata, Oreochrysum parryi, Thalictrum fendleri,* and *Viola canadensis.*

Physical setting.—The absence or minor occurrence of *Vaccinium* spp. suggests a moister nature and generally warmer than normal temperature for the *Abies lasiocarpa* series. This type occurs on all but the driest south-facing aspects, and on all landscape positions, other than ridgetops, at elevations of 9,200 to 10,500 feet (2,800 to 3,200 m). Slopes vary from gentle to very steep. Soils typically have argillic horizons and are Cryoboralfs or Cryoborolls. Occasionally, Cryorthents occur.

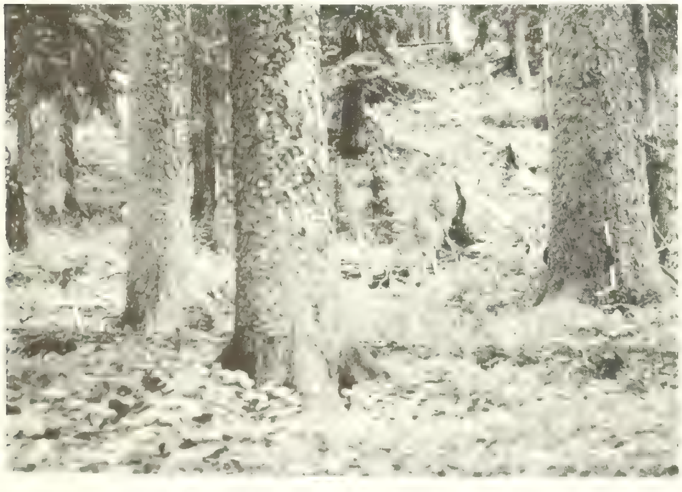

Figure 10.—*Abies lasiocarpa/Erigeron eximius* habitat type, San Juan Mountains. The tree supporting the scale-reference rod is approximately 39 inches (1 m) in diameter.

Adjacent habitat types.—On cooler and drier sites it adjoins *Vaccinium* dominated types. It intergrades with the ABCO/EREX HT at lower elevations. Often the type occurs in frost pockets within the elevational range of the *Abies concolor* series. Such frost pockets favor growth of *Abies lasiocarpa* and *Picea engelmannii* (Daubenmire and Daubenmire 1968).

Comments.—Fire has played a major role in the ABLA/EREX HT and extensive *Populus tremuloides* stands now occur within it. The undergrowth in these *Populus* communities is rich in forbs.

Among the habitat types of the *Abies lasiocarpa* series, overgrazing tends to occur most frequently in this type. Unlike situations in other habitat types in the series, *Poa pratensis* sod may develop in the ABLA/EREX HT in response to heavy livestock grazing. Large volumes of browse for elk and deer are produced.

As with most of the *Abies lasiocarpa* series, high precipitation and snowpack accumulation give this habitat type a high watershed value. Timber productivity ranges from moderate to high. The presence of *Pseudotsuga* as an important seral tree (minor climax in some areas) provides flexibility for timber management and opportunities for developing mixed species stands.

The *Abies lasiocarpa/Erigeron eximius* habitat type has previously been described as the *Abies lasiocarpa/Erigeron superbus* habitat type by Moir and Ludwig (1979). In this report, and in Fitzhugh et al.,[9] the name *Erigeron superbus* has been changed to *E. eximius* based on the nomenclature of Weber and Johnston (1979). The *Abies lasiocarpa/Lathyrus arizonica* habitat type of northern Arizona (Moir and Ludwig 1979) is similar to the ABLA/EREX HT described here. Weakly similar habitat types occur throughout the Rocky Mountains. An *Abies lasiocarpa/Berberis repens* habitat type has been reported in Utah that is identifiable with the ABLA/EREX HT (Pfister 1972). Peet (1981) describes a similar montane ravine forest community in Rocky Mountain National Park, Colorado. *Abies lasiocarpa/Clintonia uniflora* and *Abies lasiocarpa/Pachistima myrsinites* habitat types in the northern Rockies occur in environments similar to those described here (Daubenmire and Daubenmire 1968, Pfister et al. 1977, Steele et al. 1981).

Picea pungens Series

This series is restricted to cold-moist environments throughout the mixed conifer zone. Although widespread geographically, the areal extent of the *Picea pungens* series is relatively minor since topoedaphic features—sheltered slopes, frost pockets and perennially moist soils—conducive to development of *P. pungens* dominated forests form a minor component of the landscape.

Vegetation.—As a rule, overstories of the *Picea pungens* series are highly mixed. In frost pockets, *Abies lasiocarpa* and *Picea engelmannii* occur as minor components of many stands, as in the PIPU/LIBO HT, while comparatively warm sites include *Pinus ponderosa*, as in the PIPU/FEAR HT. *Pseudotsuga menziesii* is typically codominant with *Picea pungens*, while *Abies concolor* and *Pinus flexilis* are typically of secondary importance or absent. *Populus tremuloides* is the major tree species of seral stands.

The generally favorable moisture conditions result in a rich species mixture within this series. Moist sites are dominated by such forb species as *Artemisia franseriodes*, *Erigeron eximius*, *Fragaria americana*, *Oreochryrum parryi*, and *Thalictrum fendleri*, while drier sites exhibit a rich assortment of graminoids, including *Carex foenea*, *Danthonia parryi*, *Festuca arizonica*, *Muhlenbergia montana*, and *Poa fendleriana*.

Physical setting.—Examples of this series are most frequently encountered on lower slopes protected from extreme sun and wind. Elevations range from 7,900 to 9,200 feet (2,400 to 2,800 m). Soils are highly varied but are rarely lithic. Cryic soils are encountered in the PIPU/LIBO HT and occasionally in the PIPU/EREX HT, while all other habitat types in the series are represented by frigid, udic soils.

Adjacent habitat types.—Depending on elevation, the moist habitat types in the *Picea pungens* series adjoin herb-rich habitat types in the *Abies lasiocarpa* and *Abies concolor* series. Drier habitats in the series are adjacent to graminoid dominated habitats in the *A. concolor* series.

Comments.—Pfister (1972) questioned the successional status of *Picea pungens*. He suggested that where *P. pungens* occurs in association with *Abies lasiocarpa* or *A. concolor*, it must be considered seral because it is the least shade-tolerant of the three species. In this study, *P. pungens* was occasionally present and reproducing successfully even in stands containing a complement of *Abies* spp., and no evidence was found to suggest the eventual elimination of *P. pungens*. Consequently, the recognition of a *Picea pungens* climax series is justified, especially since *P. pungens* appears to be indicative of specific environmental conditions.

Heavy disturbance by both grazing and fire is widespread in this series. Careful evaluation of successional *Populus tremuloides* forests may suggest placing them in the *Picea pungens* series, depending on the presence or absence of *P. pungens* regeneration.

Management options vary widely within this series. Timber productivity is moderate and *Picea engelmannii*, *Pseudotsuga menziesii*, and *Pinus ponderosa* may all be considered for management. Domestic forage production ranges from low in the PIPU/LIBO HT to high in the PIPU/FEAR HT, and big game forage is good throughout the series. Snow accumulations are often significant and serve to heighten watershed opportunities within the series. Scenic attributes are important because the characteristic lower slope positions of the series are near roads, trails, and campgrounds.

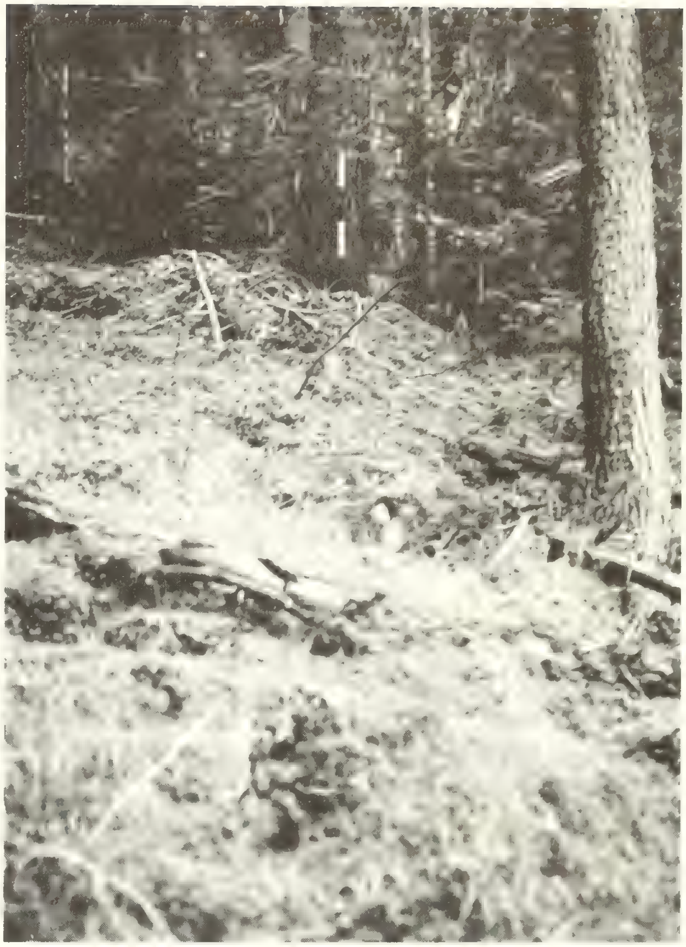

Figure 11.—*Picea pungens/Linnaea borealis* habitat type, San Juan Mountains. In this plot, moss cover is high (60%).

Picea pungens/Linnaea borealis habitat type (PIPU/LIBO; Colorado blue spruce/twinflower)

This rare habitat type was found only in the northern Sangre de Cristo Range in New Mexico and in the San Juan Mountains of Colorado.

Vegetation.—*Picea pungens* and *Pseudotsuga menziesii* codominate the overstory. *Pinus flexilis* and *Abies concolor* commonly occur. The successional status of *A. concolor* in this habitat type is uncertain. *A. lasiocarpa* and *Picea engelmannii* occur as minor components of some stands in frost pockets.

Favorable moisture conditions result in a rich assemblage of shrub and herb species within this habitat type (fig. 11). In addition to abundant *Linnaea borealis*, other shrubs characterizing the undergrowth include *Juniperus communis*, *Pachistima myrsinites*, *Rubus parviflorus*, and *Vaccinium* spp. Graminoids and forbs such as *Artemisia franseriodes*, *Carex foenea*, *Erigeron eximius*, *Fragaria* spp., *Lathyrus* spp., *Orthilia secunda*, and *Thalictrum fendleri* also are commonly found in the undergrowth.

Physical setting.—The PIPO/LIBO HT is encountered most commonly on steep, northerly, lower slopes protected from extreme sun and wind between elevations of 8,200 to 9,200 feet (2,500 and 2,800 m). Soils include Cryoborolls and Cryochrepts.

Adjacent habitat types.—The PIPU/LIBO HT commonly adjoins such species-rich habitat types as ABLA/EREX, ABLA/VAMY-LIBO, or ABLA/RUPA.

Comments.—This is the most mesic of the *Picea pungens* habitat types. Previously, Moir and Ludwig (1979) described this type as a phase of a *Picea pungens-Pseudotsuga menziesii* habitat type. The phase was upgraded to habitat type status after further sampling clearly indicated its distinctiveness. In the northern Rockies, outside the range of *Picea pungens*, the *Picea/Linnaea borealis* habitat type described by Pfister et al. (1977) is weakly related to the *Picea pungens/Linnaea borealis* habitat type described here.

Forage production is poor for domestic stock but good for deer and elk. Timber productivity is moderate. Heavy winter snow accumulations limit access.

Picea pungens/Erigeron eximius habitat type (PIPU/EREX; Colorado blue spruce/forest fleabane)

This habitat type occurs in all major mountain ranges within the study area.

Vegetation.—Overstories are similar to those of the PIPU/LIBO HT. *Abies lasiocarpa* and *Picea engelmannii* are less frequent associates, however, as the sites are generally warmer than those delineated by *Linnaea borealis.*

Typically, the undergrowth is highly variable in both composition and total cover. The moist nature of the habitat type is characterized by high forb cover, in which *Erigeron eximius* is diagnostic (fig. 12). In drier situations no diagnostic species occur with consistently high cover, but *Fragaria americana* and *Oreochrysum parryi* are common. Graminoid cover is characteristically low throughout the type except that Carex foenea is occasionally well represented. Further investigation may yield data in support of distinguishing phases within this varied habitat type.

Physical setting.—The PIPU/EREX HT occurs at elevations ranging from 8,200 to 9,200 feet (2,500 to 2,800 m) on moderate to steep lower slopes. This type may be expected on any slope exposure. Soils vary from Typic Udorthents to Eutric Glossoboralfs.

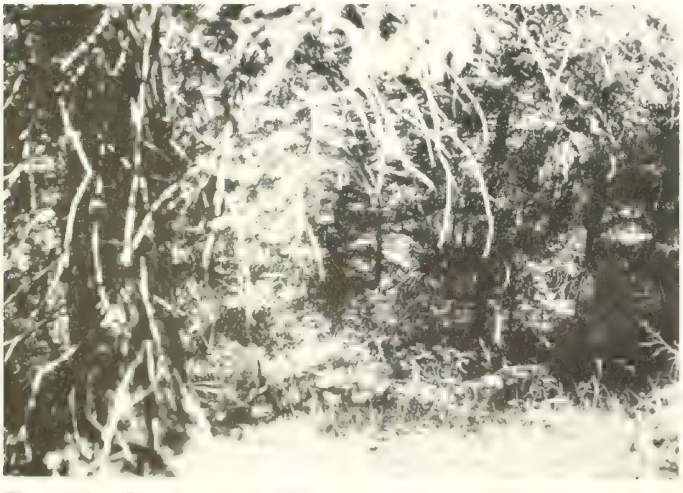

Figure 12.—*Picea pungens/Erigeron eximius* habitat type, San Juan Mountains. The undergrowth species composition is mesophytic herbs.

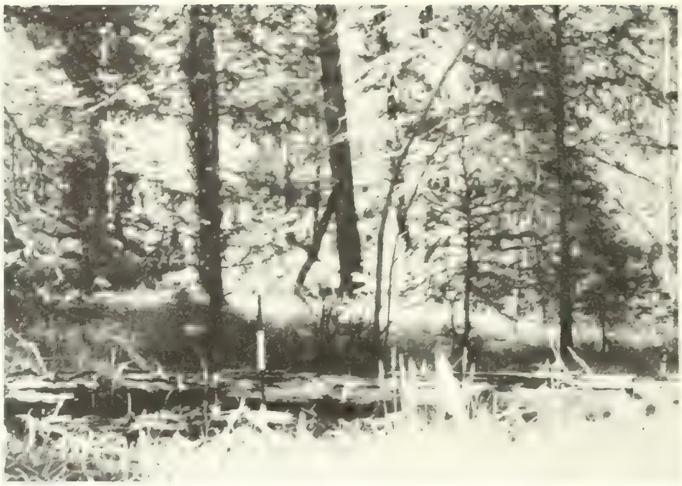

Figure 13.—A *Picea pungens/Carex foenea* habitat type, Jemez Mountains, with a well-developed undergrowth dominated by graminoids (50% cover of *C. foenea* in this plot).

Adjacent habitat types.—Lower elevation ecotones are with the ABCO/EREX HT, while at higher elevations, ecotones are formed with the ABLA/EREX HT.

Comments.—Heavy disturbance by both grazing and fire make plot selection difficult in this type. The type is widespread, however, and careful evaluation of successional forests, largely *Populus tremuloides* forb-rich communities, within the range of this type is necessary to determine the correct habitat type. Particular attention should be paid to the presence or absence of *Picea pungens* regeneration.

The *Picea pungens/Erigeron eximius* habitat type of southern New Mexico and Arizona was described by Fitzhugh et. al.[9] Similarly, affinities occur with the *Picea pungens-Picea engelmannii/Erigeron superbus* habitat type described in the White Mountains of Arizona (Moir and Ludwig 1979), except that *P. engelmannii* is a relatively minor component of the PIPU/EREX HT in northern New Mexico and southern Colorado.

The lower slope position of this type places it adjacent to many roads, trails, and campgrounds. Thus, the habitat type has important scenic qualities.

Picea pungens/Carex foenea habitat type (PIPU/CAFO; Colorado blue spruce/spruce sedge)

This minor habitat type occurs in the Jemez Mountains of New Mexico and the San Juan Mountains of Colorado.

Vegetation.—Overstories typically exhibit codominance of *Picea pungens* and *Pseudotsuga menziesii*, with *Pinus ponderosa* important in some stands as a seral species. *Abies concolor* generally is absent or minor. Undergrowths are characterized by abundant *Carex foenea* and often high coverage of *Fragaria* spp. and *Geranium richardsonii* (fig. 13).

Physical setting.—This habitat type occurs on northerly facing canyon sideslopes at elevations of 8,500 to 9,000 feet (2,590 to 2,740 m). Slope steepness typically is gentle to moderate. Dominant soils are Typic Dystrandepts.

Adjacent habitat types.—Adjoining habitat types are PIPU/FEAR at lower elevations and PIPU/EREX or ABCO/ACGL at higher elevations. The type often borders grassy meadows.

Comments.—As with other habitat types that support high cover of palatable graminoids, the PIPU/CAFO HT often is used by grazing animals. The generally moderate terrain and close proximity to water further promote grazing use. Many stands are within summer grazing allotments. The type is relatively minor in areal extent and therefore is probably less important for management. Moir and Ludwig (1979) previously described this type.

Pseudotsuga menziesii and *Pinus ponderosa* are important commercial trees occurring within this type; however, growth is moderate at best.

Picea pungens/Arctostaphylos uva-ursi habitat type (PIPU/ARUV; Colorado blue spruce/kinnikinnik)

This is a minor habitat type, occurring primarily in the San Juan Mountains.

Vegetation.—*Picea pungens, Pseudotsuga menziesii,* and *Pinus ponderosa* frequently codominate in the overstory. Occasionally, *Abies concolor* and *Pinus flexilis* are also important. *Arctostaphylos uva-ursi* is the characteristic understory dominant and *Festuca arizonica, Fragaria ovalis,* and *Juniperus communis* are frequently important (fig. 14).

Physical setting.—The PIPU/ARUV HT occurs on warm, dry, moderately steep, south slopes and ridges at elevations of 7,900 to 9,200 feet (2,410 to 2,800 m). It seldom is found on midslopes.

Adjacent habitat types.—Warmer sites merge to the PIPU/FEAR or the ABCO/ARUV HT, while cooler site ecotones are with the PIPU/CAFO HT.

Comments.—Moir and Ludwig (1979) previously described this type as the *Arctostaphylos uva-ursi* phase of their *Picea pungens-Pseudotsuga menziesii* habitat type. The distinctiveness of the PIPU/ARUV HT, as observed by further sampling in northern New Mexico and southern Colorado, supported raising the phase to the habitat type level. Within the *Picea pungens* series, only the PIPU/FEAR HT is characteristically found in warmer, drier situations.

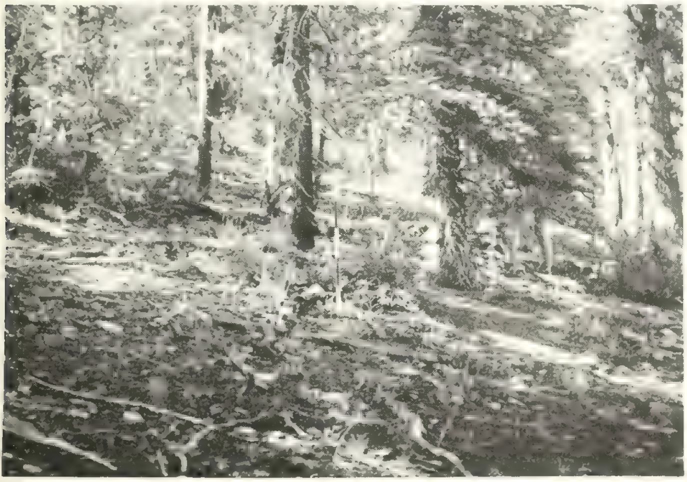

Figure 14.—*Picea pungens/Arctostaphylos uva-ursi* habitat type, San Juan Mountains. *A. uva-ursi* and *Juniperus communis* are well represented in this plot.

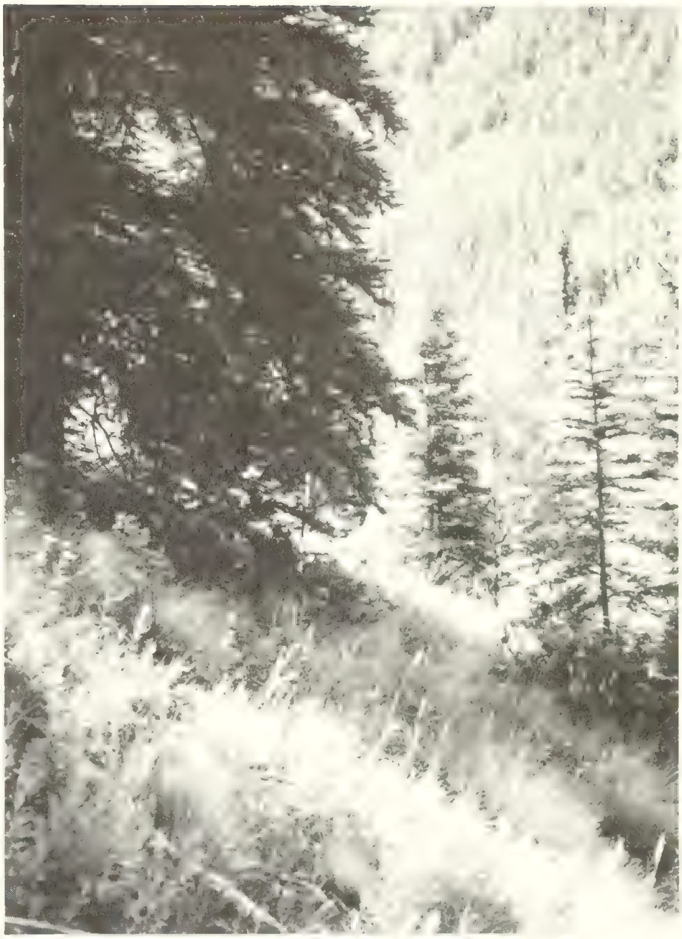

Figure 15.—*Picea pungens/Festuca arizonica* habitat type, San Juan Mountains. As shown here, stands are open, allowing the shade-intolerant *F. arizonica* to dominate the undergrowth.

Picea pungens/Festuca arizonica habitat type (PIPU/FEAR; Colorado blue spruce/Arizona fescue)

This habitat type occurs primarily in the Jemez Mountains of New Mexico and in the San Juan Mountains of Colorado.

Vegetation.—Overstories are similar to those described for the PIPU/ARUV HT. Undergrowths are characterized by high cover of a rich assortment of graminoids (fig. 15). *Carex foenea, Danthonia parryi, Festuca arizonica, Koeleria macrantha, Muhlenbergia montana, Poa fendleriana,* and *Sitanion hystrix* are found in most plots. Important forbs include *Erigeron formosissimus, Fragaria* spp., *Lathyrus* spp., and *Potentilla hippiana.*

Physical setting.—In contrast to the PIPU/CAFO HT on northerly slopes, this type generally occurs on warmer southwesterly slopes. Elevations vary from 8,200 to 9,200 feet (2,500 to 2,800 m) and slopes are moderate to steep. Soil subgroups are highly varied and include Udic Argiborolls and Haploborolls, Lithic Haploborolls, Eutric Glossoboralfs, Typic Dystochrepts, and Andeptic Udorthents.

Adjacent habitat types.—The ABCO/FEAR HT is encountered in slightly drier situations and the PIPU/CAFO or the ABCO/CAFO HT's in more mesic areas.

Comments.—The *Picea pungens/Festuca arizonica* habitat type, was also reported in southern Arizona and New Mexico (Fitzhugh et al.[9]). The PIPU/FEAR HT represents the warmest and driest of *P. pungens* dominated forests. It is moderately extensive, particularly when considered in combination with the closely related ABCO/FEAR HT. The high palatability of *Festuca arizonica* makes forage management an important consideration in this type.

Abies concolor Series

The *Abies concolor* series occurs at mid-elevations and is the most widespread mixed conifer series.

Vegetation.—Overstories are highly mixed, sometimes with seven coniferous species growing together in the same stand—*Abies concolor, Abies lasiocarpa, Picea engelmannii, Picea pungens, Pinus flexilis, Pinus ponderosa*, and *Pseudotsuga menziesii*. However, the presence and relative proportion of these species depends on moisture-temperature relationships. In all cases, more successful reproduction of *A. concolor* is diagnostic of this series. Early seral communities are dominated by *Populus tremuloides* in mesic situations, and by *Quercus gambelii* on comparatively xeric sites.

The undergrowth is also highly variable. Among the diagnostic species, *Vaccinium* spp. occurs on cold sites, *Festuca arizonica* on warm sites, *Quercus gambelii* on dry sites, and *Erigeron eximius* on moist sites. Stands rich in shrubs, herbs, graminoids, or with depauperate undergrowths such as the ABCO/Sparse HT, are all represented in this series. Undergrowths may resemble those of the *Pseudotsuga menziesii* series on dry sites or the *Abies lasiocarpa* series on cold sites.

Physical setting.—Elevations range from 7,900 to 10,200 feet (2,410 to 3,110 m). Settings vary from cold-moist sites having cryic soils to warm-dry sites having frigid-udic soils.

Adjacent habitat types.—The *Abies concolor* series exhibit the most complex ecotones of any forested series in the study area (Layser and Schubert 1979). At upper elevations, the series grades to the *Abies lasiocarpa* series, while cool-moist sites at the same elevation feature the *Picea pungens* series. Lower elevation sites support the *Pseudotsuga menziesii* series and on the most xeric sites the *Pinus ponderosa* series.

Comments.—Management options are varied within the *Abies concolor* series. Timber productivity may be high for *Pseudotsuga menziesii* in the ABCO/EREX HT. Grazing opportunities for domestic stock are maximized in the ABCO/FEAR HT. Big game utilization may be exceptionally high in the ABCO/ACGL HT. Heavy snow accumulation will produce high water yields in the ABCO/VAMY HT. Varied topographical and biological conditions within the series add to the esthetics.

Basically, the *Abies concolor* series is ecologically similar to the *Abies grandis* series of the northern Rocky Mountains described by Pfister et al. (1977) and Steele et al. (1981). Both the *A. concolor* and the *A. grandis* series lie between the drier *Pseudotsuga menziesii* series and the cooler *A. lasiocarpa* series.

Fire is a major influence in maintaining many plant communities in this series. *Abies concolor* is relatively susceptible to fire (Brown and Davis 1973) and is more highly shade-tolerant than *Pinus ponderosa* and *Pseudotsuga menziesii* (Baker 1950). Thus, many habitat types within the *A. concolor* series are dominated by *Pinus ponderosa* and *Pseudotsuga menziesii* in mid-seral stages, with *A. concolor* steadily gaining dominance as succession proceeds.

Abies concolor/Vaccinium myrtillus habitat type (ABCO/VAMY; white fir/myrtle blueberry)

This minor habitat type occurs in the San Juan, Sangre de Cristo, and Jemez Mountains.

Vegetation.—Overstories are highly mixed, with some stands comprised of up to seven species, including *Abies concolor, Abies lasiocarpa, Picea engelmannii, Picea pungens, Pinus flexilis, Pinus ponderosa*, and *Pseudotsuga menziesii*.

Acer glabrum, Amelanchier alnifolia, Arctostaphylos uva-ursi, Mahonia repens, Pachistima myrsinites, Rubus parviflorus, and *Symphoricarpos oreophilis* are shrubs that often codominate the conspicuous *Vaccinium* spp. layer of the undergrowth (fig. 16). Among the many forb species usually present are *Erigeron eximius, Fragaria ovalis*, and *Lathyrus* spp.

Physical setting.—This habitat type occurs at approximately 8,500 to 9,200 feet (2,590 to 2,800 m), which is below the elevational limits of *Abies lasiocarpa* and *Picea engelmannii* dominance. It occurs on steep, cold, northerly slopes. Soils are Cryochrepts, Cryoborolls, and Cryorthents.

Adjacent habitat types.—The ABCO/VAMY HT type adjoins ABLA/VAMY stands at higher elevations and herb-rich mixed conifer stands at lower elevations.

Comments.—This type is found on the coldest sites in the *Abies concolor* series. Because of the infrequent occurrence of the type, it is relatively unimportant for management. *Pseudotsuga menziesii* could be favored in timber management, but *P. menziesii* dominance would be difficult to maintain in such a mixed conifer environment.

Livestock forage production potential is low. Big game browse may be heavy, and thinning the overstory will increase shrub cover.

The ABCO/VAMY HT has not been described previously in the southern Rocky Mountains. However, it is closely related to the *Pseudotsuga menziesii/Pachistima myrsinites* habitat type described in the central Rockies (Hoffman and Alexander 1980) and weakly related to *Abies grandis* and *Pseudotsuga menziesii/Vaccinium globulare* habitat types of the northern Rockies (Pfister et al. 1977, Steele et al. 1981).

Abies concolor/Erigeron eximius habitat type (ABCO/EREX; white fir/forest fleabane) Mexico

This type is relatively rare in Colorado, but is common in the Jemez Caldera region and the Sangre de Cristo Range of New Mexico.

Vegetation.—Overstories are highly complex. *Abies concolor* and *Pseudotsuga menziesii* codominate, but *Picea pungens* and *Pinus flexilis* may be important. In frost pockets, *Abies lasiocarpa* and *Picea engelmannii* also may occur. *Pinus ponderosa* is accidental or minor. Seral communities are dominated by *Populus tremuloides*.

The ABCO/EREX HT is a herb-rich habitat type (fig. 17). *Artemisia franseriodes, Bromopsis ciliata, Carex foenea, Erigeron eximius, Fragaria* spp., *Lathyrus* spp., *Oreochrysum parryi*, and other moist-site herbs exhibit characteristically high cover values. Relative to the closely related ABCO/ACGL HT, shrubs are generally less important. Canopy removal may cause substantial increases in shrub coverage. Distinguishing the ABCO/EREX HT from the ABCO/ACGL HT on seral sites is difficult. However, herb-richness is diagnostic of the *Erigeron* type.

Physical setting.—All slopes, aspects, and landforms other than ridges are represented, but elevations cluster narrowly between 9,200 and 9,500 feet (2,800 and 2,900 m). Sites are moist and protected from extreme sun and wind. Soils include Haploborolls and Dystrochrepts.

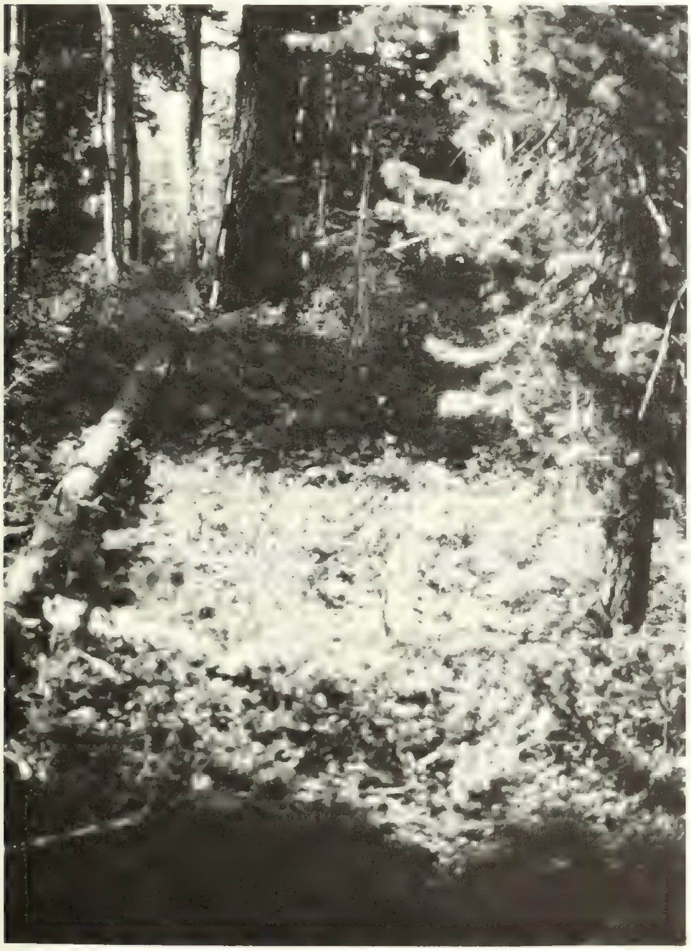

Figure 16.—***Abies concolor/Vaccinium myrtillus*** **habitat type, San Juan Mountains.**

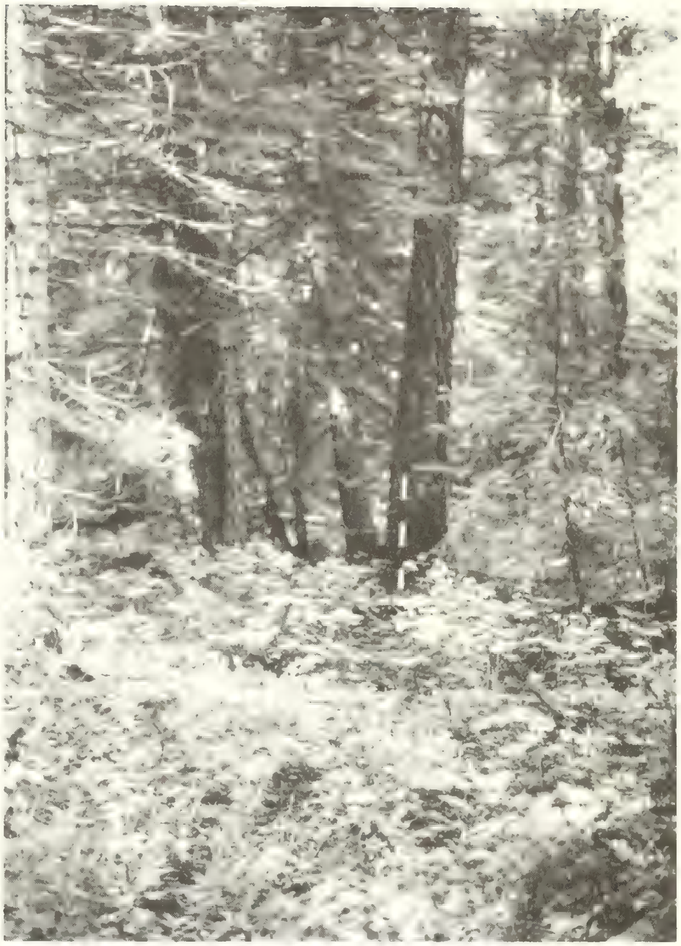

Figure 17.—***Abies concolor/Erigeron eximius*** **habitat type, San Juan Mountains. Herb and sub-shrub diversity and cover are high, with *E. eximius* up to 30%.**

Adjacent habitat types.—The major ecotone is with the ABCO/ACGL HT. The two types intergrade, with the *Erigeron* type generally found on deeper soils.

Comments.—Moir and Ludwig (1979) originally described this type as the *Abies concolor-Pseudotsuga menziesii/Erigeron superbus* habitat type. To shorten the name, *Pseudotsuga menziesii*, the less shade tolerant of the two trees, was dropped. Also, to reflect the revised taxonomy of Weber and Johnston (1979), *Erigeron superbus* was changed to *E. eximius*. Fitzhugh et al.[9] have recognized this as a distinct type in southern Arizona and New Mexico. General site characteristics are weakly comparable with *Abies grandis/Clintonia uniflora* habitat type of Montana and central Idaho (Pfister et al. 1977, Steele et al. 1981).

Timber productivity may be high for *Pseudotsuga*. Livestock find little forage except in early successional stands. However, wildlife browse is favorable except in winter when heavy snow accumulations limit access.

Abies concolor/Acer glabrum habitat type (ABCO/ACGL; white fir/Rocky Mountain maple)

The type occurs throughout the study area except for the Dolores Mesa area, which is located at the western edge of the San Juan Mountains of Colorado and is outside the range of *Abies concolor*.

Vegetation.—Tree species present are the same as those found in the ABCO/EREX HT. Shrubs dominate the undergrowth (fig. 18). *Acer glabrum, Amelanchier alnifolia, Jamesia americana, Mahonia repens, Pachistima myrsinites, Physocarpus monogynus*, and *Symphoricarpos oreophilus* often have high cover values. Although typically lower in cover, many of the same herbs are found in the ABCO/ACGL HT as in the ABCO/EREX HT.

Physical setting.—This is one of the most varied types with respect to topographic and vegetational characteristics. All slope aspects are represented, and elevations span from 8,200 to 9,850 feet (2,500 to 3,000 m). The type occurs predominantly on lower slopes, but many examples can be found on mid and upper slopes.

This type typically occurs on relatively shallow, often skeletal, soils on very steep slopes. Borolls, Boralfs, and Ochrepts were all sampled within the type.

Adjacent habitat types.—The ABCO/ACGL HT intergrades to ABCO/EREX HT in more mesic areas and to the ABCO/QUGA HT in more xeric situations. The type forms a lower elevation limit of many subalpine species.

Comments.—This type is one of the most widespread in the mixed conifer forest. It has previously been described in many forests in Arizona and New Mexico (Alexander et al. 1984, Fitzhugh et al.,[9] Moir and Ludwig 1979) and is related to the *Pseudotsuga menziesii/Pachistima myrsinites* habitat type of central and northern Colorado (Hess and Wasser,[8] Hoffman and Alexander 1980). Weakly related types are represented by the foothill ravine forest community of Rocky Mountain National Park, Colorado (Peet 1981), and the *Abies grandis/Acer glabrum* habitat type of central Idaho (Steele et al. 1981).

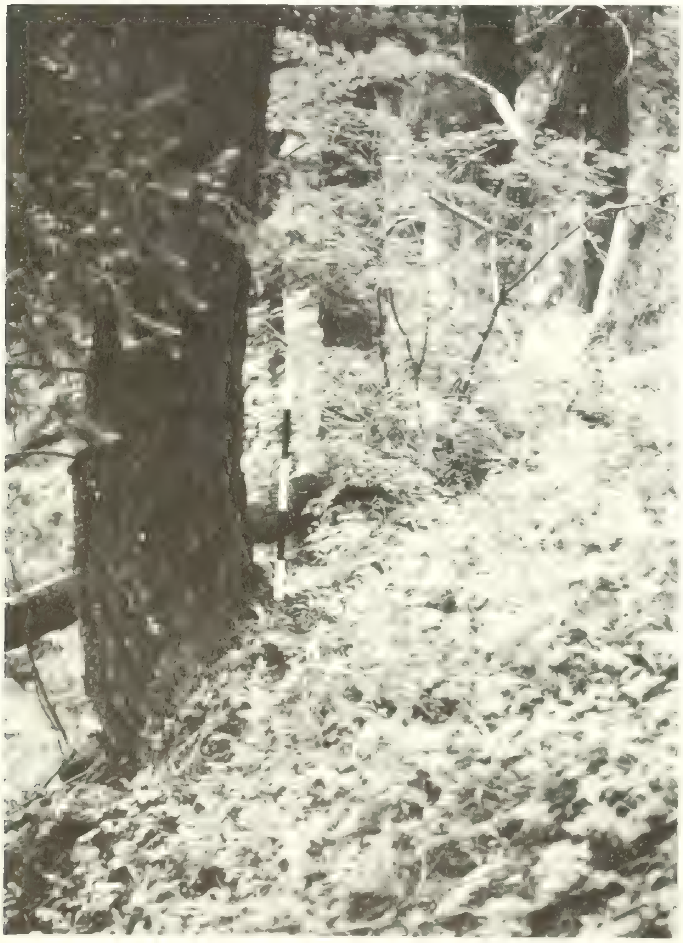

Figure 18.—*Abies concolor/Acer glabrum* habitat type, San Juan Mountains. *A. glabrum* is important in the undergrowth.

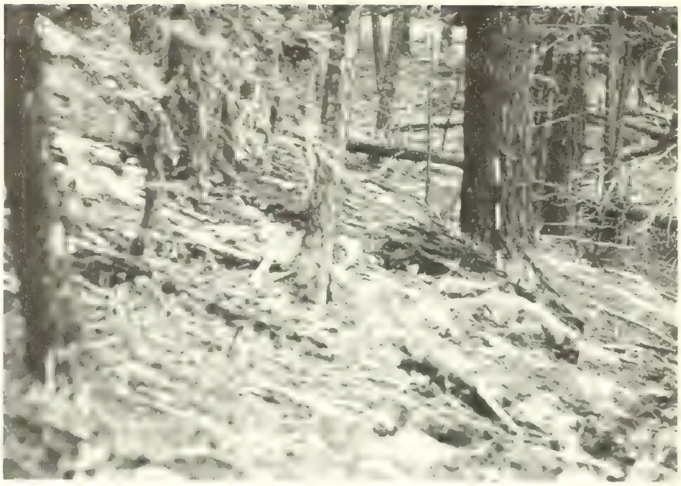

Figure 19.—*Abies concolor*/Sparse habitat type, San Juan Mountains. The sparse undergrowth cover shown is characteristic of this type.

Because of the cool, moist conditions characteristic of this habitat type, fires are mostly light, erratic, and infrequent (Moir and Ludwig 1979). The erratic nature of fires has resulted in mosaics in forest structure within this type.

Timber productivity is moderate. *Pseudotsuga menziesii* should regenerate well except when competition with shrubs is severe, which may be particularly significant when shrubs are released upon removal of the canopy.

Old-growth stands offer scant forage for livestock, and the typically steep slopes impede access. The type supplies prime forage and cover for big game. The shrubs provide abundant browse. Multistoried shrub layers increase microhabitat diversity for birds (Fitzhugh et al.[9]).

Abies concolor/Sparse habitat type (ABCO/Sparse; white fir/sparse undergrowth)

This habitat type is widespread within the study area.

Vegetation.—Overstories exhibit codominance of *Abies concolor* and *Pseudotsuga menziesii. Pinus flexilis, Pinus ponderosa, Picea pungens*, and *Juniperus scopulorum* are sometimes present.

Undergrowths are sparse, with only *Symphoricarpos oreophilos* ever attaining coverage in excess of 5% (fig. 19).

Physical setting.—This relatively dry habitat type occurs on canyon sideslopes and ridges of all aspects between the elevations of 8,200 and 9,850 feet (2,500 and 3,000 m). Slopes are steep to very steep. Soil suborders include Ochrepts, Borolls, Boralfs, and Orthents.

Adjacent habitat types.—Adjoining habitat types include ABCO/ACGL on moister sites and ABCO/QUGA on warmer sites. Cooler environments bordering this habitat type support forests dominated by *Abies lasiocarpa* habitat types.

Comments.—Management for all but water and wildlife is marginal as timber productivity and forage yields are low. In this study, some plots within the habitat type fit the description of the *Pseudotsuga menziesii/Physocarpus monogynus* habitat type described in northern New Mexico by Moir and Ludwig (1979). However, only two plots supported *Physocarpus* and furthermore, their site characteristics were closely comparable to those of other plots in the ABCO/Sparse HT. Thus, recognition of a distinct *Pseudotsuga menziesii/Physocarpus monogynus* habitat type does not seem warranted at this time. Within such *Physocarpus*-dominated undergrowths, nevertheless, soils are invariably skeletal and site potential is exceptionally low.

The ABCO/Sparse HT has previously been described in Arizona and New Mexico (Alexander et al. 1984, Fitzhugh et al.,[9] Moir and Ludwig 1979). Weak similarities exist with xeric *Pseudotsuga* forest communities in northern Colorado (Peet 1981) and the *Pseudotsuga menziesii/Arnica cordifolia* habitat type described in the northern Rocky Mountains (Pfister et al. 1977, Steele et al. 1981).

In most cases, herb growth is likely limited by seasonal soil water deficits and shading (Moir and Ludwig 1979). Caution is necessary when keying to this habitat type since in some cases depauperate stages of other habitat types also may key to the ABCO/Sparse HT. Similarly, sparsity in other habitat types may result from intensive or prolonged wildlife browsing and grazing and should not be confused with normal sparseness in the ABCO/Sparse HT.

Abies concolor/Arctostaphylos uva-ursi habitat type (ABCO/ARUV; white fir/kinnikinnik).

This type is of minor importance, but it occurs throughout the study area.

Vegetation.—Overstories are characterized by *Abies concolor* and *Pseudotsuga menziesii*, with *Pinus ponderosa* a major seral associate. *Arctostaphylos uva-ursi* dominates the undergrowth along with *Pachistima myrsinites* in some stands. Few other species ever attain 5% cover (fig. 20). *Arctostaphylos uva-ursi* cover is highest in sunlit openings.

Physical setting.—This type, seldom occurring on midslopes, is found most commonly on ridgetops and occasionally on lower slopes. Slopes are moderate to steep, facing all exposures. Elevations range from 7,900 to 9,500 feet (2,410 to 2,900 m). Soils are Typic Udorthents and Typic Dystrochrepts.

Adjacent habitat types.—The ABCO/ARUV HT represents a dry, cool environment within the zone of *Abies concolor-Pseudotsuga menziesii* codominance. In dry, warm situations *Pinus ponderosa* attains climax status within the range of *Arctostaphylos uva-ursi* and in dry, cold situations *Abies concolor* forests, with *Vaccinium* spp. undergrowths, are encountered.

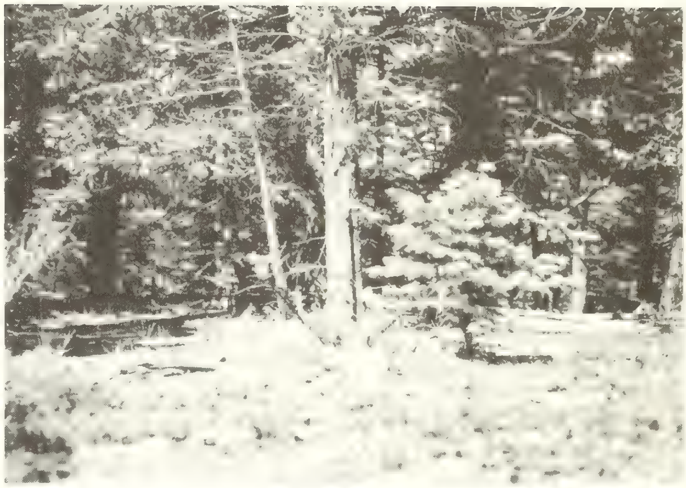

Figure 20.—*Abies concolor/Arctostaphylos uva-ursi* habitat type, San Juan Mountains. In this plot, *A. uva-ursi* cover is 15% and *Festuca arizonica* cover is 2%.

Comments.—This relatively minor type is perhaps best suited for wildlife use. Timber productivity is low, and xeric conditions of most stands may hinder regeneration following logging. Because of low snow accumulations, forests in this habitat type often provide winter range for wildlife.

Pfister et al. (1977) reported a *Pseudotsuga menziesii/Arctostaphylos uva-ursi* habitat type in Montana that is weakly similar to the type described here.

Abies concolor/Festuca arizonica habitat type (ABCO/FEAR; white fir/Arizona fescue)

This relatively minor type primarily occurs in the Jemez and San Juan Mountains of New Mexico.

Vegetation.—*Abies concolor* and *Pseudotsuga menziesii* codominate. *Pinus ponderosa* is an important seral or minor climax species. *Danthonia parryi*, *Festuca arizonica*, *Muhlenbergia montana*, and *Poa fendleriana* attest to the grassy character of the undergrowth (fig. 21). Shrub and forb cover is generally minor.

Physical setting.—This type occurs on all aspects and slope positions within the elevational range of 8,200 to 10,200 feet (2,500 to 3,110 m). Slopes are moderate to steep. Climates are seasonally dry and are near the warm limits of mixed conifer forests (Moir and Ludwig 1979). Soils include Argiborolls and Dystrochrepts.

Adjacent habitat types.—In warmer situations, the ABCO/FEAR HT adjoins the PSME/FEAR or PIPO/FEAR HT's, while cooler situations favor *Picea pungens* dominance.

Comments.—As with other grass-dominated habitat types, grazing by both domestic stock and elk will be an important management consideration. Historically, fires were common within this type and served as a thinning agent to maintain open stands (Moir and Ludwig 1979). Growth of grasses in the undergrowth is best expressed in openings and, thus, a fire management program would enhance grazing opportunities. Caution is necesary in utilizing prescribed fire, however, because years of fire suppression have favored heavy fuel accumulations and dense stands of young trees, conditions that are conducive to highly destructive fires (Biswell et al. 1973).

Timber management probably favors either *Pseudotsuga menziesii* or *Pinus ponderosa*, or a combination of the two. However, *P. ponderosa* is near its mesic limits in this type and its regeneration may be difficult because of competition from *Abies* and *Pseudotsuga* (Moir and Ludwig 1979).

This type has been reported previously in Arizona and New Mexico (Fitzhugh et al.,[9] Moir and Ludwig 1979).

Abies concolor/Quercus gambelii habitat type (ABCO/QUGA; white fir/Gambel oak)

This type, which occurs throughout the southern Rocky Mountains, is the most widespread mixed conifer habitat type within the study area.

Vegetation.—*Abies concolor* and *Pseudotsuga menziesii* codominate the overstory. *Pinus flexilis*, *Pinus ponderosa*, and *Populus tremuloides* are common seral species. *Quercus gambelii* is the most characteristic undergrowth species, often forming nearly impenetrable thickets (fig. 22). *Mahonia repens*, *Rosa* spp., and *Symphoricarpos oreophilus* are often important shrubs. *Jamesia americana* is an important shrub on moist sites in this type. Other than *Carex rossii*, graminoid cover is scant, although *Bromopsis ciliata* and *Poa fendleriana* are fairly constant. Forb species diversity is often high, but total cover is generally less than 10%.

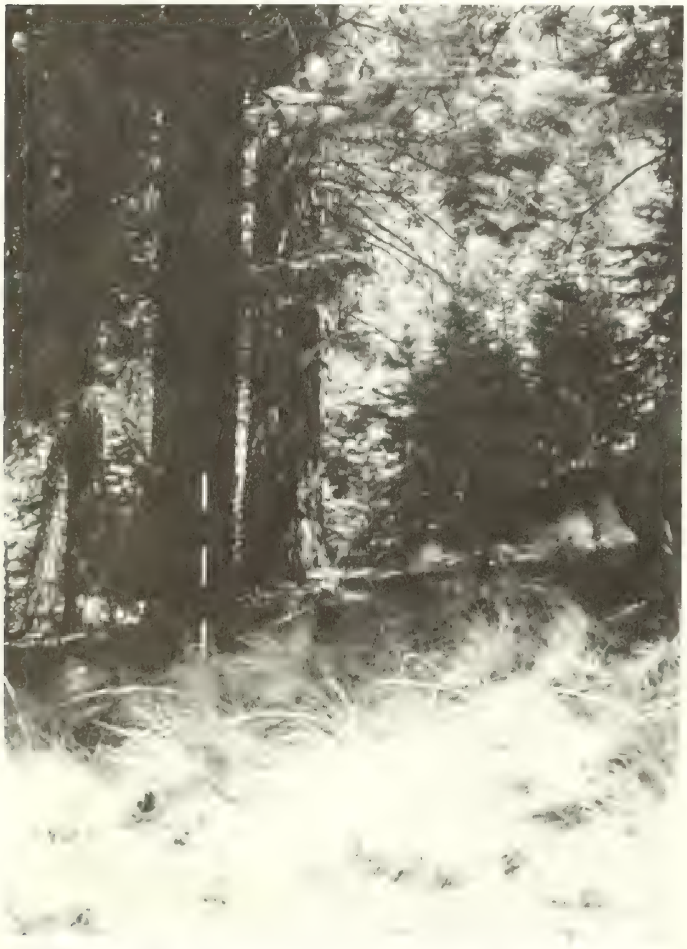

Figure 21.—*Abies concolor/Festuca arizonica* habitat type, San Juan Mountains. Common species in this plot are *F. arizonica*, *Muhlenbergia montana*, and *Arctostaphylos uva-ursi*.

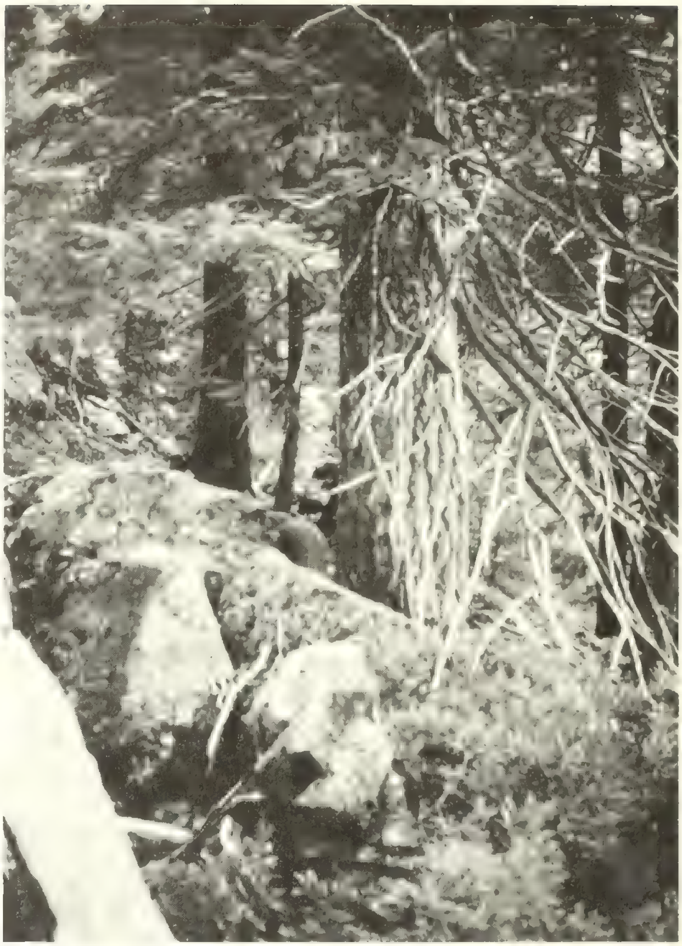

Figure 22.—*Abies concolor/Quercus gambelii* habitat type, San Juan Mountains. *Q. gambelii* is diagnostic in the undergrowth.

Physical setting.—The type occurs on all landscape positions and aspects at elevations from 7,900 to 9,500 feet (2,410 to 2,900 m). Slopes vary from gentle to very steep. Soils are often in lithic subgroups.

Adjacent habitat types.—The ABCO/QUGA HT often adjoins *Pseudotsuga menziesii* or *Pinus ponderosa* forests lacking an *Abies* component. Wetter or cooler sites merge to the ABCO/ACGL HT, while drier or warmer sites have grassy undergrowths, similar to the ABCO/FEAR HT.

Comments.—This type has been previously described in Arizona and New Mexico (Alexander et al. 1984, Fitzhugh et al.,[9] Moir and Ludwig 1979). Fire is a major ecological component of these forests, and the high *Quercus* cover may relate to its ability to reproduce vegetatively after fire. Timber productivity is moderate. The type provides valuable cover and browse for deer populations.

Pinus flexilis Series

Pinus flexilis/Arctostaphylos uva-ursi habitat type (PIFL/ARUV; limber pine/kinnikinnik)

The PIFL/ARUV HT is minor in occurrence and is the only habitat type in the *Pinus flexilis* series. The few samples were taken in the northern portion of the Sangre de Cristo Mountains in New Mexico and in the Wet Mountains of Colorado.

Vegetation.— *Pinus flexilis* dominates, or is codominant with *Pseudotsuga menziesii* in the overstory; *Picea engelmannii* is often subdominant (fig. 23). The undergrowth is characterized by a conspicuous *Arctostaphylos uva-ursi* layer and the common occurrence of *Juniperus communis*. Herbaceous cover seldom exceeds trace amounts.

Physical setting.—Elevations cluster around 9,850 feet (3,000 m) and landforms are steep southerly-facing upper slopes. Soils typically are skeletal and are Dystric Cryochrepts or Typic Cryorthents.

Adjacent habitat types.—Most commonly, the PIFL/ARUV HT borders the ABLA/VAMY HT that is found on less exposed and cooler environments within the same elevational zone. Transitions to the ABCO/Sparse HT also are to be expected.

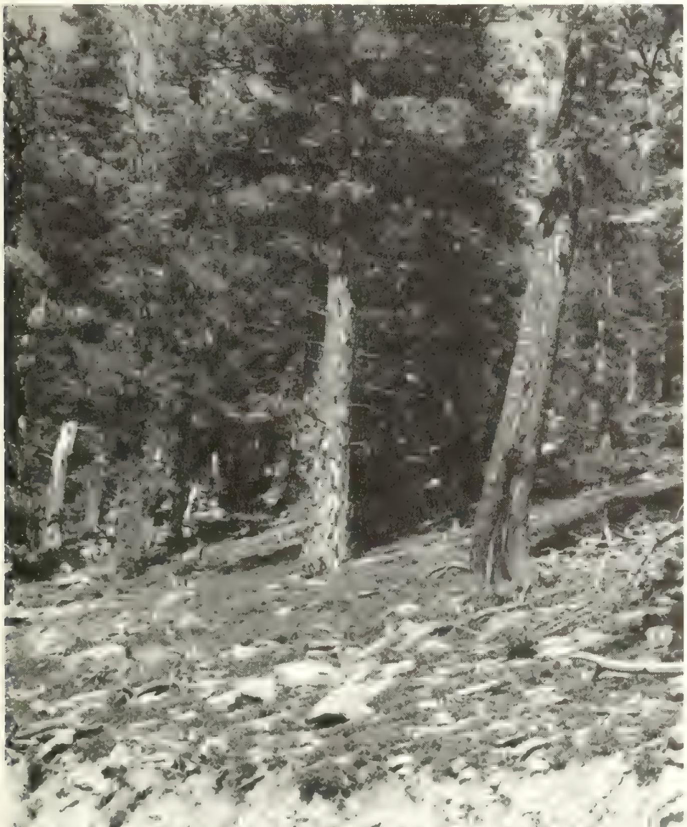

Figure 23.—*Pinus flexilis/Arctostaphylos uva-ursi* habitat type, Sangre de Cristo Mountains. *A. uva-ursi* is conspicuous in the undergrowth.

Comments.—The relatively warm winter climate and presence of big game forage species in this type make it an important winter range. The large seeds of *Pinus flexilis* provide food for birds and small mammals. Livestock use is very light because of difficult accessibility and low graminoid production.

The PIFL/ARUV HT represents drier sites within the *Abies lasiocarpa/Vaccinium* spp. zone. The exposed conditions favor snow movement rather than accumulation, and the well-drained, skeletal soils store inadequate water to support *Abies lasiocarpa* forest. Thus, the stands remain open, favoring the growth of heliophytic *Arctostaphylos uva-ursi*.

Timber productivity is low. Management would typically favor *Pseudotsuga menziesii* because *Pinus flexilis* is generally not an economically important species. High surface soil temperatures combined with low soil moisture may hamper regeneration following logging (Pfister et al. 1977).

Highly similar types have been described elsewhere. These include the *Pseudotsuga menziesii/Arctostaphylos uva-ursi* habitat type in southern New Mexico (Fitzhugh et al.[9]), the xeric *Pinus contorta-Pseudotsuga* forest communities in northern Colorado (Peet 1981), and the *Pseudotsuga menziesii/Arctostaphylos uva-ursi* habitat type in Montana (Pfister et al. 1977). Very close affinities are shared with the *Pseudotsuga menziesii, Arctostaphylos uva-ursi, Juniperus communis* habitat types in south-central Colorado (Shepherd[6]), and the *Pinus flexilis/Juniperus communis* habitat type in northern Colorado, central Idaho, and Montana (Hoffman and Alexander 1980, Pfister et al. 1977, Steele et al. 1981).

Pseudotsuga menziesii Series

The *Pseudotsuga menziesii* series is relatively minor in the study area and is represented by only two habitat types: PSME/FEAR and PSME/QUGA.

Vegetation.—In addition to *Pseudotsuga menziesii*, *Pinus ponderosa* often dominates the overstory. Warmer sites within the series may also support *Juniperus scopulorum* and *Pinus edulis*. *Abies concolor* is absent or minor. Early successional forests are typically dominated by either *Populus tremuloides*, in the PSME/FEAR HT, or *Quercus gambelii*, in the PSME/QUGA HT.

The undergrowth varies from grassy *Festuca arizonica* to nongrassy, *Quercus gambelii* dominated situations.

Physical setting.—Steep slopes characterize this series. Elevations range from 6,550 to 9,500 feet (2,000 to 2,900 m). Soils generally have udic moisture regimes at higher elevations and ustic moisture regimes at lower elevations. Temperature regimes are frigid.

Adjacent habitat types.—Warm, dry sites favor habitat types of the *Pinus ponderosa* series, while ecotones in moist environments are with *Abies concolor* habitat types.

Comments.—*Pseudotsuga menziesii* has the greatest ecological amplitude of any coniferous species in the study area. In the northern Rocky Mountains, Rehfeldt (1974) demonstrated substantial genetic variation among *P. menziesii* populations from contrasting habitats. This genetic diversity contributes to the broad ecological amplitude. However, *P. menziesii* is less shade-tolerant than *Abies* spp. and is not considered climax in stands with *Abies* spp. Thus, the *P. menziesii* series is relatively minor in areal extent since most stands where it is important are codominated by more shade-tolerant species. North of the study area, in central and northern Colorado, *Abies concolor* does not occur; thus, some habitat types listed here within the *Abies concolor* series may appear as *P. menziesii* climax types in other locations.

The series generally does not contain productive timberlands. Management would typically favor *Pseudotsuga menziesii*. Forage production for livestock is high in the *Festuca arizonica* dominated forests.

Pseudotsuga menziesii/Festuca arizonica habitat type (PSME/FEAR; Douglas-fir/Arizona fescue)

This is a minor type found in the mountain ranges of southern Colorado and the northern Sangre de Cristo Mountains in New Mexico.

Vegetation.—With the exception of *Abies concolor*, all coniferous species of mixed conifer forests may be expected within this type. *Festuca arizonica* dominance is diagnostic within the highly varied undergrowth (fig. 24). *Koeleria macrantha* is always present and *Muhlenbergia montana*, with up to 15% cover, often occurs as well. *Arctostaphylos uva-ursi* and *Poa fendleriana* are sometimes well represented.

Physical setting.—This habitat type occurs most frequently on steeply sloping southerly exposures from 8,850 to 9,500 feet (2,700 to 2,900 m) elevation. Surface rock cover in excess of 15% is common. Soils include Borolls, Boralfs, and Orthents.

Adjacent habitat types.—Close similarities occur between the PSME/FEAR HT and the ABCO/FEAR HT. The main diagnostic feature of the PSME/FEAR is the absence of *Abies concolor*, suggesting warmer and drier conditions. The PSME/QUGA HT occurs in rockier situations. The PSME/FEAR HT often adjoins meadows.

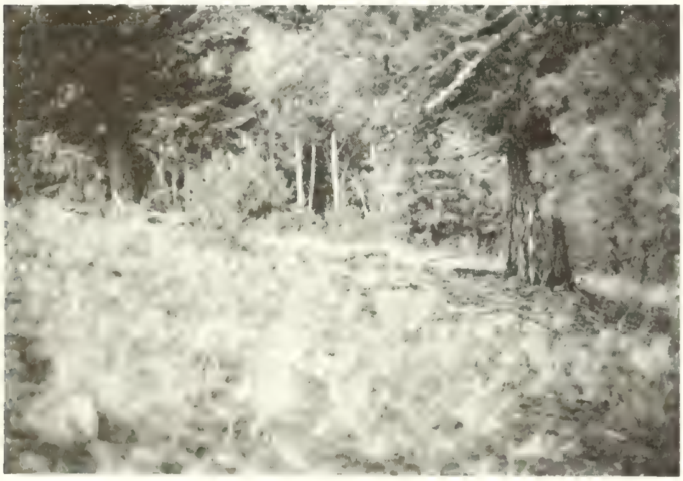

Figure 24.—*Pseudotsuga menziesii/Festuca arizonica* habitat type, San Juan Mountains. The undergrowth in this open-forest plot is dominated by *F. arizonica* and *Muhlenbergia montana*.

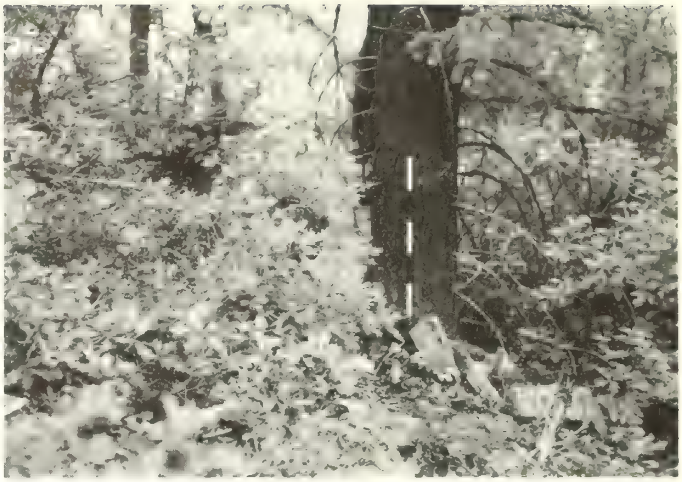

Figure 25.—*Pseudotsuga menziesii/Quercus gambelii* habitat type, *Quercus gambelii* phase, San Juan Mountains. The combined cover of the shrubs *Amelanchier alnifolia, Q. gambelii, Rosa woodsii*, and *Symphoricarpos oreophilus* equals 60% in this plot.

Comments.—As with other *Festuca*-dominated types, grazing is a prime management consideration. Deer, elk, and bighorn sheep find winter cover and forage in this type.

Timber productivity is low. *Pseudotsuga menziesii* and *Pinus ponderosa* are commercial species, but grass competition hinders regeneration following logging.

The type has been recognized in Arizona and New Mexico by Moir and Ludwig (1979) and Fitzhugh et al.[9] In Colorado, Shepherd[6] described a complex of eight *Pseudotsuga menziesii* habitat types having grassy undergrowths dominated by *Festuca arizonica* that are identifiable with the PSME/FEAR HT. Similarities occur with the *Pseudotsuga menziesii/Festuca idahoensis* habitat type described in the northern Rockies (Pfister et al. 1977, Steele et al. 1981).

Pseudotsuga menziesii/Quercus gambelii habitat type (PSME/QUGA; Douglas-fir/Gambel oak)

This type occurs throughout the study area.

Vegetation.—In addition to *Pseudotsuga menziesii, Pinus ponderosa* is often a dominant in the overstory.

Undergrowths vary from nongrassy *Quercus gambelii* dominated (fig. 25) to relatively grassy *Quercus gambelii-Festuca arizonica* associations. *Amelanchier alnifolia, Symphoricarpos oreophilus, Carex geyeri*, and *Muhlenbergia montana* are sometimes important.

Two phases are recognized: (1) the *Festuca arizonica* (FEAR) phase, with *Festuca arizonica* present and grass species more evident in the undergrowth; and (2) the *Quercus gambelii* (QUGA) phase, with *Festuca arizonica* absent and shrub species dominant.

Physical setting.—Slopes range from moderate to very steep; elevations vary from 6,550 to 9,200 feet (2,000 to 2,800 m), with stands occurring on all aspects. Soils are predominately Eutroboralfs, Glossoboralfs, and Argiborolls.

Adjacent habitat types.—This type occupies a position in the environmental gradient between the ABCO/QUGA and the PIPO/QUGA HT's. The three habitat types constitute the most widespread forests in the study area.

Comments.—As in the other habitat types where *Quercus gambelii* is diagonostic, oak is the most conspicuous feature of the vegetation. Grasses are commonly important in the undergrowth, especially in the FEAR phase. This habitat type has broad possibilities for management, ranging from forage utilization to timber production, which is low to moderate. Multilayered canopies in the undergrowth in this shrubby type support varied bird species (Fitzhugh et al.[9]).

This PSME/QUGA HT has been reported in Arizona and New Mexico (Alexander et al. 1984, Fitzhugh et al.[9]). Hess and Wasser[8] described a highly similar type in central Colorado, the *Pinus ponderosa/Quercus gambellii/Carex geyeri* habitat type. Very weak affinities are shared with mesic foothill woodland communities of northern Colorado (Peet 1981) and the *Pseudotsuga menziesii/Symphoricarpos oreophilus* habitat type from the northern Rockies (Pfister et al. 1977, Steele et al. 1981).

Pinus ponderosa Series

The *Pinus ponderosa* series is found throughout the low-elevation sites of the study area.

Vegetation.—*Pinus ponderosa* is the least shade-tolerant tree of the seven species considered in this study. Therefore, only those stands where *P. ponderosa* dominates the regeneration are considered to lie within the *Pinus ponderosa* series. In moister environments within the *P. ponderosa* series, *Pseudotsuga menziesii* may occur in minor amounts, and in warm-dry situations, *Pinus edulis* and *Juniperus scopulorum* are important. *Quercus gambelii* is a common seral species; however, in areas lacking *Quercus*, succcession to *P. ponderosa* may be direct.

Dry-site undergrowths are similar to adjacent non-forest communities. Grasses such as *Bouteloua gracilis*, *Muhlenbergia montana*, *Poa fendleriana*, and *Schizachyrium scoparium* are characteristic. Moist-site undergrowths are similar to the *Pseudotsuga menziesii* series and also to the drier habitats in the *Abies concolor* series. In these cases, *Arctostaphylos uva-ursi*, *Quercus gambelii*, and *Festuca arizonica* may be important.

Physical setting.—The series may be found on any slope or aspect between elevations of 5,900 to 9,500 feet (1,800 to 2,900 m). Soils are generally frigid and ustic.

Adjacent habitat types.—The first forest type encountered above low-elevation grasslands and pinyon-juniper woodlands is *Pinus ponderosa*. Except for *Pinus edulis* and *Juniperus* spp., *P. ponderosa* is the most drought-resistant conifer in the study area. Following *P. ponderosa* in drought-resistance is *Pseudotsuga menziesii* (Pharis 1966). Higher elevational ecotones are with the *P. menziesii* series. In some mesic situations, ecotones to the *Abies concolor* series occur.

Comments.—Surface fires at intervals of 5 to 12 years are a natural component of the *Pinus ponderosa* cover type and serve to maintain open parklike stands throughout much of the series (Cooper 1960, Weaver 1951). However, the advent of modern fire suppression has resulted in the establishment of dense patches of young trees in many areas. Shade and needle accumulation under such patches hinders development of the herbaceous undergrowth (Daubenmire and Daubenmire 1968). In such situations, habitat type identification may be difficult because of low coverage or absence of indicator species.

Undisturbed forests are rarer in the *Pinus ponderosa* series than in others. Damage from overgrazing has been particularly severe, resulting in localized elimination of species and conversions of grass-rich undergrowths to those rich in weeds. Dominance of such forb species as *Hymenoxys* spp., *Taraxacum officinale*, and *Xanthocephalum sarothrae* indicates overgrazing, as does the abundance of certain indicator grasses—*Bromus tectorum*, *Poa pratensis* and, to some extent, *Poa fendleriana* and *Sitanion hystrix*. Such pervasive alteration of the undergrowth adds to the difficulty in determining the correct habitat type. In some cases, soil disturbance may be so severe that the ability of such sites to support the predisturbance plant association no longer exists.

Similarly, the ease of access in the *Pinus ponderosa* series and the desirable properties of *P. ponderosa* lumber has resulted in heavy timber harvests throughout the series. The alteration of the tree canopy further adds to the difficulty in identifying habitat types in the *P. ponderosa* series.

In general, forests in the *Pinus ponderosa* series are less productive than the more mesic series at higher elevations. Natural regeneration is generally difficult because favorable seedcrops, suitable seedbeds, and soil moisture must be coincidental. Dense grass cover and heavy livestock grazing may impede regeneration. As many *P. ponderosa* habitat types are rich in graminoids, livestock grazing is a prime management direction. Recovery from overgrazing may require decades. Abundant big game browse is found in shrubby habitat types, and more open stands may provide important big game winter range.

Pinus ponderosa/Arctostaphylos uva-ursi habitat type (PIPO/ARUV; ponderosa pine/kinnikinnik)

This is a minor habitat type found in the Jemez and Sangre de Cristo Mountains of New Mexico and the Wet Mountains of Colorado.

Vegetation.—*Pinus ponderosa* dominates the tree layer, with *Pseudotsuga menziesii* having minor importance in some areas. *Abies concolor* is infrequent or absent. *Arctostaphylos uva-ursi* is conspicuous as an undergrowth dominant and is diagnostic of this type. *A. uva-ursi* coverage ranges from 30% to 70% and, generally, it is the sole dominant species (fig. 26). Graminoids that are occasionally important include *Carex heliophila*, *C. rossii*, *Festuca arizonica*, and *Muhlenbergia montana* (up to 5% cover). Shrub cover other than *A. uva-ursi* is generally low; however, *Quercus gambelii* is often present. In the sparse forb layer, few species ever exceed 1% cover; *Lathyrus* spp. is important locally.

Physical setting.—This type is confined primarily to lower slopes and ridges at elevations of 7,700 to 9,200 feet (2,350 to 2,800 m). The type occurs on all exposures and slopes from gentle to very steep. Ridge soils in this type belong to lithic subgroups, while lower slope soils have moderately deep profiles.

Adjacent habitat types.—The PIPO/ARUV HT intergrades with the ABCO/ARUV HT on ridges, the ABCO/QUGA HT on upper north-facing slopes, and the PIPO/QUGA HT on upper south-facing slopes.

On lower slopes, adjoining habitats include such grass dominated types as the PIPO/FEAR HT and in moister situations the PIPU/FEAR HT. When the PIPO/ARUV HT occurs on lower south-facing slopes, it often intergrades to the ABCO/ARUV HT as the exposure shifts northward.

Comments.—The PIPO/ARUV HT has not been described previously. However, it shares many characteristics of the PSME/ARUV HT as defined in the mountains of southwestern New Mexico by Fitzhugh et al.[9] The PIPO/ARUV HT is not widespread in the southern Rockies, because *Arctostaphylos uva-ursi* is generally absent in mountain floras south of the San Juan and Sangre de Cristo Mountains, but is a major element of many mountain floras to the north.

Site quality is poor for timber production. Wildlife use is moderate.

Pinus ponderosa/Festuca arizonica habitat type (PIPO/FEAR; ponderosa pine/Arizona fescue)

This habitat type is widespread within the study area.

Vegetation.—*Pinus ponderosa* is the climax dominant, but *Pseudotsuga menziesii* is minor in some stands. Dominance by grasses and, sometimes, forbs is diagnostic of this type, with shrubs distinctly of secondary importance (fig. 27). *Quercus gambelii* never exceeded 5% cover in sampled stands. *Koeleria macrantha, Poa fendleriana*, and *Sitanion hystrix* frequently are important grasses. *Achillea millefolium* ssp. *lanulosa, Antennaria rosea, Erigeron formosissimus* and *Potentilla hippiana* are locally abundant forbs.

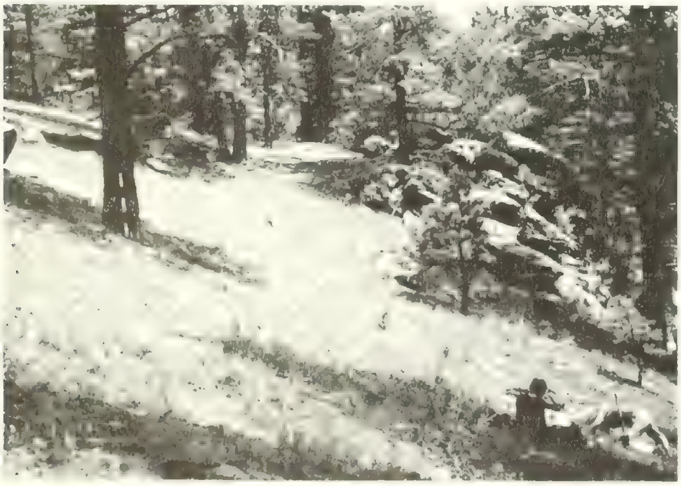

Figure 26.—A *Pinus ponderosa/Arctostaphylos uva-ursi* habitat type, Wet Mountains at 9,000 feet (2,740 m). This plot is an open stand with undergrowth dominated by *A. uva-ursi*.

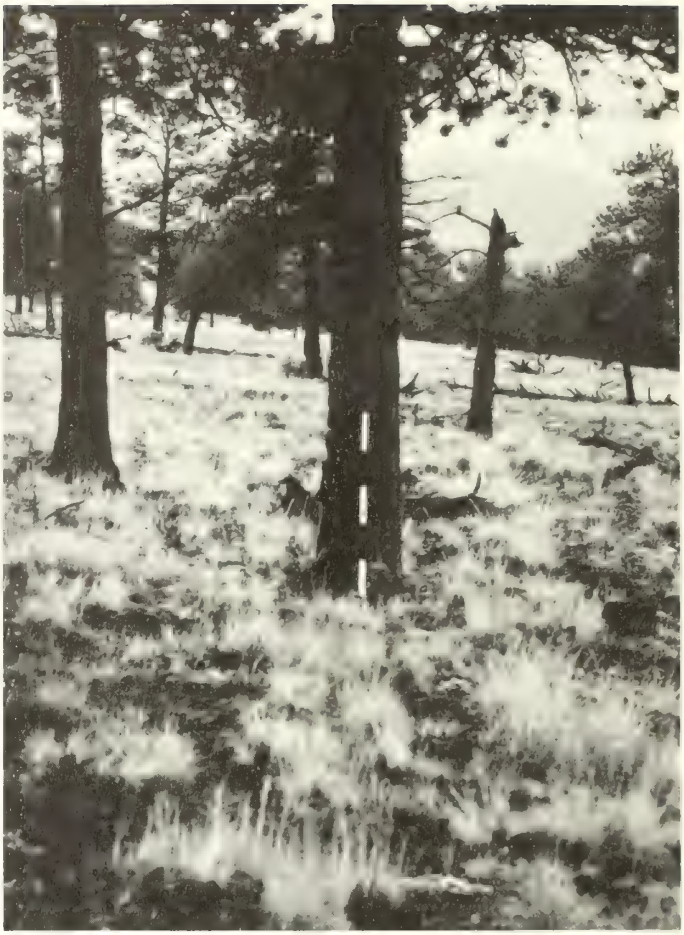

Figure 27.—*Pinus ponderosa/Festuca arizonica* habitat type, *Danthonia parryi* phase, San Juan Mountains. *D. parryi, F. arizonica*, and *Muhlenbergia montana* are all well represented in this plot.

The PIPO/FEAR HT has been divided into three phases: (1) *Danthonia parryi* (DAPA) phase, with *Danthonia parryi* present and other graminoids usually conspicuous; (2) *Festuca arizonica* (FEAR) phase, with *Danthonia parryi* scarce or absent and *Festuca arizonica* conspicuous; and (3) *Bouteloua gracilis* (BOGR) phase, with *Danthonia parryi* absent and *Bouteloua gracilis* present.

Pinus ponderosa is the climax dominant tree throughout the type, with *Festuca arizonica* and *Muhlenbergia montana* consistently important undergrowth grasses. *Danthonia parryi* has up to 60% cover in plots where it delineates a phase. The *Bouteloua gracilis* phase represents the hot, dry extreme of the type and features *Pinus edulis* and *Juniperus* spp. in the overstory.

Physical setting.—The type occurs on all aspects and landscape positions from lower slopes to ridges within an elevational range of 7,200 to 9,500 feet (2,190 to 2,900 m). Slopes vary from gentle to very steep. Soils are predominantly Borolls, but Boralfs and, to a lesser degree, Orthents and Ochrepts are also represented. Generally, the soils are low in coarse fragments.

Adjacent habitat types.—The PIPO/FEAR HT adjoins the PIPO/QUGA HT, FEAR phase, as soils become rockier. Where conditions become more mesic, this type is adjacent to forests dominated by the ABCO/FEAR HT. Drier sites support less *Festuca arizonica*, with *Bouteloua gracilis* increasing in importance.

Comments.—This habitat type is the coolest and wettest of the grassy *Pinus ponderosa* habitat types. Also, soils are typically deeper in this habitat type than in other related *Pinus* types. Heavy grass cover favors surface fires; the absence of fire would tend to result in denser tree canopy cover and subsequently reduced grass cover.

Muhlenbergia montana is often a codominant grass, especially in the FEAR phase. However, it has wide ecological amplitude, being important in many contrasting habitat types and, thus, has low indicator value. *Festuca arizonica* has a relatively narrow ecological amplitude and is a highly diagnostic species.

High grass cover makes this habitat type particularly desirable for livestock or big game range. However, overgrazing has been widespread and has reduced or, in some cases, eliminated *Festuca arizonica*. The occurrence of weedy species, such as *Bromus tectorum, Hymenoxys acaulis, H. richardsonii, Poa pratensis, Taraxacum officinale*, and *Xanthocephalum sarothrae* indicates overgrazing. At the mesic end of *Pinus ponderosa* distribution, many disturbed sites with deep loamy soils that currently lack *F. arizonica*, but are covered with the above species, probably are within the PIPO/FEAR HT. Since *Danthonia parryi* is highly palatable to livestock, the area identifiable as this phase may have been greater in the past.

The DAPA phase has not been described elsewhere; however, environmental conditions align closely with the *Festuca scabrella* phase of the *Pinus ponderosa/Festuca idahoensis* habitat type described in Montana by Pfister et al. (1977). High *Danthonia parryi* cover and relatively cool sites with deep soils characterize the phase. Site quality for tree growth within the DAPA phase is moderate. This phase is not widespread and is relatively unimportant for timber production.

The FEAR phase of this type has been described in the Mogollon Mountains (Fitzhugh et al.[9]) and is comparable to the *Pinus ponderosa/Festuca arizonica* habitat type in northern Arizona (Hanks et al. 1983). Similar stands identified as the *Pinus ponderosa/Festuca idahoensis* habitat type are recognized in the central and northern Rockies (Daubenmire and Daubenmire 1968, Hoffman and Alexander 1976, Pfister et al. 1977, Steele et al. 1981). The FEAR phase has low timber productivity.

The BOGR phase has been described in northern Arizona by Hanks et al. (1983) and in southwestern New Mexico and southeastern Arizona by Fitzhugh et al.[9] Site quality for timber production is low.

Pinus ponderosa/Quercus gambelii habitat type (PIPO/QUGA; ponderosa pine/Gambel oak)

This habitat type is found throughout the study area.

Vegetation.—*Pinus ponderosa* is the major climax dominant tree within this habitat type. *Pinus edulis* and *Juniperus scopulorum* are typically absent. *Quercus gambelii* trees and shrubs typify the undergrowths, sometimes forming impenetrable thickets (fig. 28). *Cercocarpus montanus* is another characteristic shrub. Graminoids occurring across this habitat type include *Bouteloua gracilis, Carex heliophila, C. rossii, Koeleria macrantha, Muhlenbergia montana, Poa fendleriana*, and *Sitanion hystrix. Achillea millefolium* ssp. *lanulosa* and *Artemisia ludoviciana* are the most characteristic forbs.

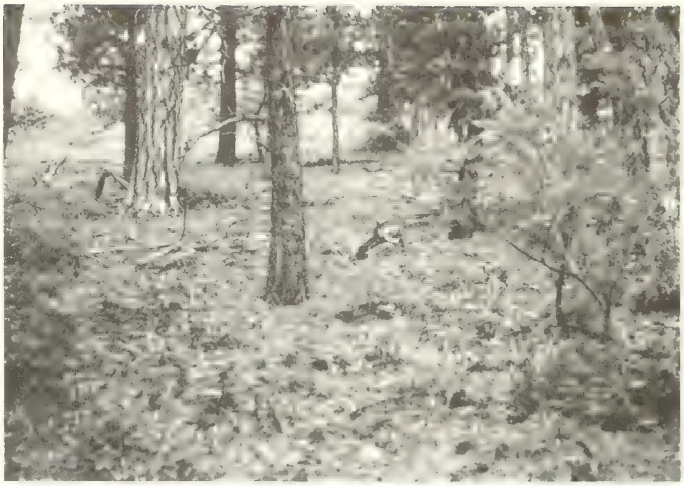

Figure 28.—*Pinus ponderosa/Quercus gambelii* habitat type, *Quercus gambelii* phase, Spanish Peaks. The undergrowth is dominated by *Q. gambelii* (35% cover).

Three phases are recognized: (1) *Festuca arizonica* (FEAR) phase, with *Festuca arizonica* present; (2) *Quercus gambelii* (QUGA) phase, with *Pinus edulis* and *Festuca arizonica* scarce or absent; and (3) *Pinus edulis* (PIED) phase, with *Pinus edulis* common as advanced regeneration.

The FEAR phase generally exhibits codominance of both *Festuca arizonica* and *Muhlenbergia montana* in the undergrowth. In the QUGA phase, few undergrowth species with high cover occur consistently. Individual forb species in this phase seldom exceed 1% cover, but *Poa fendleriana* cover averages 5% and is often diagnostic.

Physical setting.—This type encompasses considerable topographic variation. Elevations range from 6,550 to 9,200 feet (2,000 to 2,800 m). Slopes vary from gentle to very steep, and soils from shallow to deep. Typical soil subgroups include Mollic Eutroboralfs, and Typic and Lithic Arigiborolls or Eutroboralfs.

Adjacent habitat types.—As sites become wetter and/or cooler, this type intergrades to the ABCO/QUGA or PSME/QUGA HT's. In contrast, warmer and drier sites have a pinyon-juniper woodland cover. Mosaics of the PIPO/QUGA HT and grassy *Pinus ponderosa* habitat types often form on given slopes in response to microsite variations. *Quercus gambelii* typically dominates rocky sites, while grasses dominate sites with deeper soils; this is consistent with Peet's (1981) observations.

Comments.—Of 165 plots sampled in the *Pinus ponderosa* series, 61 are classified as the PIPO/QUGA HT, attesting to the widespread importance of this type in the southern Rocky Mountains.

As with all habitat types in the *Pinus ponderosa* series, fire is an important ecological factor in succession. In the PIPO/QUGA HT following a catastrophic fire, *Quer-*

cus gambelii soon forms dense thickets by extensive root sprouting. Competition with conifer regeneration is severe during this persistent *Q. gambelii* stage of succession (Hanks 1966). Certain areas where *Q. gambelii* alone dominates stands, with no hint of conifer establishment, may in fact represent a *Q. gambelii* climax series (Brown 1958).

Although livestock grazing is common in this type, dense oak thickets and a general lack of surface water are a hindrance to management in many areas; also, forage production is low. However, *Quercus gambelii* and *Cercocarpus montanus* are favorable browse species and receive moderate to heavy use by deer and elk. Big game cover often is very good; some areas may be used as winter range.

Release of *Quercus gambelii* following logging or fire results in situations that hinder regeneration of *Pinus ponderosa*. Timber productivity is generally low.

The QUGA phase of this habitat type has previously been described for southern New Mexico and southeastern Arizona (Alexander et al. 1984, Fitzhugh et al.[9]). In northern Arizona, a related *Pinus ponderosa/Festuca arizonica* habitat type, *Quercus gambelii* phase, has been described (Hanks et al. 1983). The habitat type of Hanks et al. (1983) is very similar to the FEAR phase described here, except for a shift in the balance between *Q. gambelii* and *F. arizonica* cover. Hess and Wasser[8] described a related *Pinus ponderosa/Quercus gambelii/Carex geyeri* habitat type in central Colorado. Steele et al. (1981) found a weakly related *Pinus ponderosa/Symphoricapos oreophilus* habitat type in central Idaho. Close affinities occur between the PIPO/QUGA HT, PIED phase, and that portion of the *Pinus ponderosa/Quercus gambelii* habitat type described in New Mexico and Arizona by Alexander et al. (1984) and Fitzhugh et al.[9] that has a high representation of *Pinus edulis*. Similarly, Hanks et al. (1983) described a *Pinus ponderosa/Bouteloua gracilis* habitat type, *Quercus gambelii* phase, that is comparable to the PIED phase described here.

Pinus ponderosa/Muhlenbergia montana habitat type (PIPO/MUMO; ponderosa pine/mountain muhly)

This habitat type is located mostly in the San Juan Mountains of New Mexico. Occasional examples of the type also occur in the Sangre de Cristo Mountains.

Vegetation.—*Pinus ponderosa* is the only tree consistently dominant in this habitat type. *Juniperus* spp. or *Pinus edulis* may occur as occasional trees. Grass species other than *Koeleria macrantha*, *Muhlenbergia montana*, *Poa fendleriana*, and *Sitanion hystrix* are of low frequency (fig. 29). In the absence of other indicator species, the highly constant *M. montana* is considered diagnostic. *Quercus gambelii* exhibits up to 5% cover in this habitat type. Characteristic forbs include *Arenaria fendleri*, *Erigeron flagellaris*, and *E. formosissimus*. Total forb cover is relatively low, although a moderately high number of species may occur on a given site.

Physical setting.—This habitat type characteristically is found on gently sloping ridges, mesa tops, and benches between the elevations of 7,550 and 8,500 feet (2,300 and 2,590 m). The soil surface is covered with litter, with little rock and bare soil. Soils are shallow to deep and have loamy to clayey textures with low to high coarse fragment content. Typical soil great groups include Ustorthents, Ustochrepts, and Eutroboralfs.

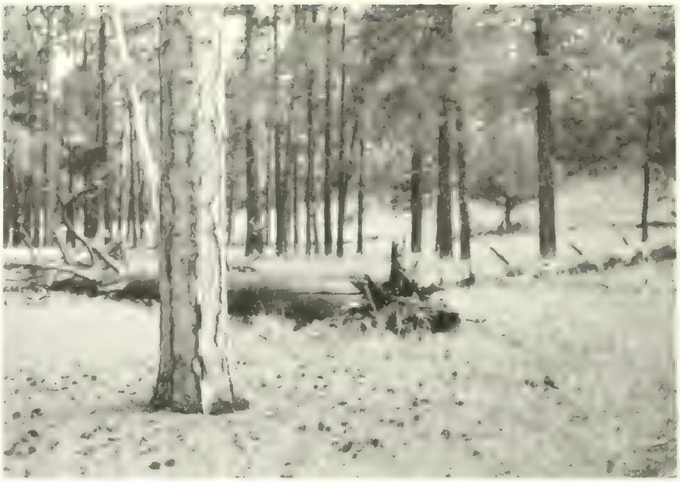

Figure 29.—*Pinus ponderosa/Muhlenbergia montana* habitat type, San Juan Mountains. In this plot, undergrowth is rich in *Koeleria macrantha, M. montana, Poa fendleriana*, and *Sitanion hystrix*.

Adjacent habitat types.—The PIPO/MUMO HT often forms a mosaic with the PIPO/QUGA HT. As site conditions become mesic, the type has ecotones with the PIPO/FEAR HT. On more xeric sites, this habitat type intergrades to the PIPO/BOGR HT.

Comments.—This habitat type has previously been described in the Mogollon Mountains of southwestern New Mexico by Fitzhugh et al.[9] Further, Peet (1981) identified xeric foothill and montane woodland communities in northern Colorado that are closely similar to the type.

Because the PIPO/MUMO HT generally occurs on gentle topography and has good forage production potential, heavy grazing has been widespread. In some areas, it is difficult to determine if the absence or low cover of such indicator species as *Festuca arizonica* or *Schizachyrium scoparium* is an artifact of disturbance that affects *Muhlenbergia montana* to a lesser extent. Timber productivity is low in this type.

Pinus ponderosa/Bouteloua gracilis habitat type (PIPO/BOGR; ponderosa pine/blue grama)

This habitat type occurs in the San Juan and Sangre de Cristo Mountains of New Mexico.

Vegetation.—Generally, *Pinus ponderosa* and *P. edulis* codominate the tree stratum. *Juniperus monosperma* and *J. scopulorum* are frequently important. *Quercus gambelii* is generally present but poorly represented; total shrub cover seldom exceeds 1%. *Bouteloua gracilis* or *Schizachyrium scoparium* is diagnostic of the type and sometimes shares high coverage with other grasses such as *Blepharoneuron tricholepis*, *Bouteloua curtipendula*, *Muhlenbergia montana*, *Poa fendleriana*, and *Sitanion hystrix* (fig. 30). *Lotus wrightii* is an important undergrowth forb on some sites.

Two phases of this habitat type are recognized: (1) *Schizachyrium scoparium* (SCSC) phase, with *Schizachyrium scoparium* well represented; and (2) *Bouteloua gracilis* phase, with *Schizachyrium scoparium* poorly represented or absent.

The SCSC phase is weakly similar to the *Pinus ponderosa/Andropogon* habitat type described in Montana by Pfister et al. (1977). The phase is most extensive on the eastern slope of the Sangre de Cristo Mountains in New Mexico, where elements of the Great Plains, such as *Schizachyrium scoparium*, are common. *S. scoparium* is highly palatable and susceptible to damage from excess grazing pressure.

The BOGR phase has been described in northern Arizona by Hanks et al. (1983) and in southwestern New Mexico and southeastern Arizona by Fitzhugh et al.[9] This phase and the SCSC phase represent sites at or near the hot-dry extremes of *Pinus ponderosa* growth.

Physical setting.—The type occurs on all aspects, from gentle to steep lower slopes to mesa tops and benches. Elevations range from 6,250 to 8,550 feet (1,900 to 2,610 m). Soils vary from sandy to clayey textures and from low to high coarse fragment content. Taxonomically, soils in this type are quite variable.

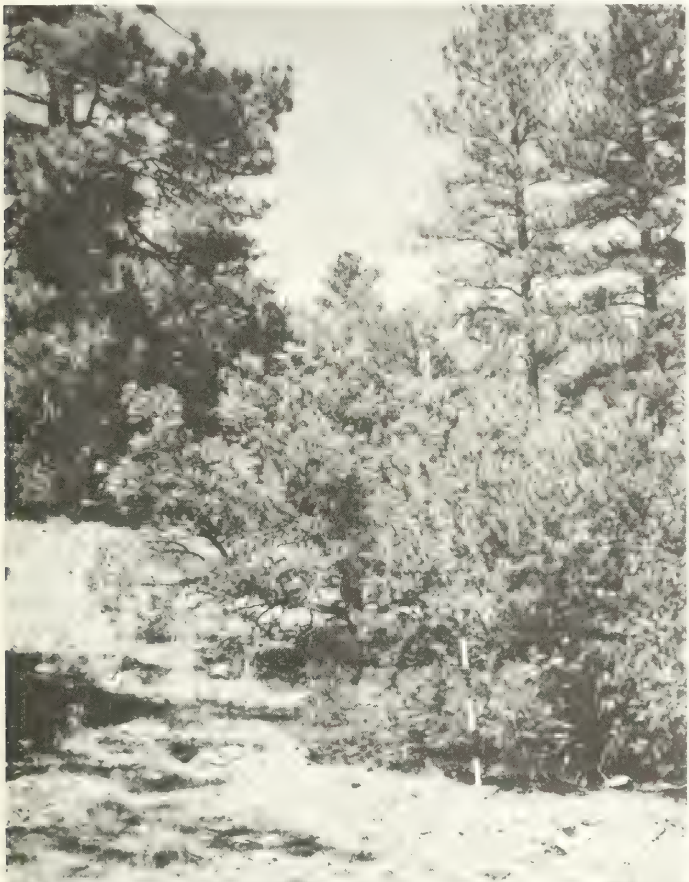

Figure 30.—A *Pinus ponderosa/Bouteloua gracilis* habitat type, *Schizachyrium scoparium* phase, Sangre de Cristo Range at 7,300 feet (2,220 m). *B. curtipendula, B. gracilis*, and *S. scoparium* are common in the undergrowth.

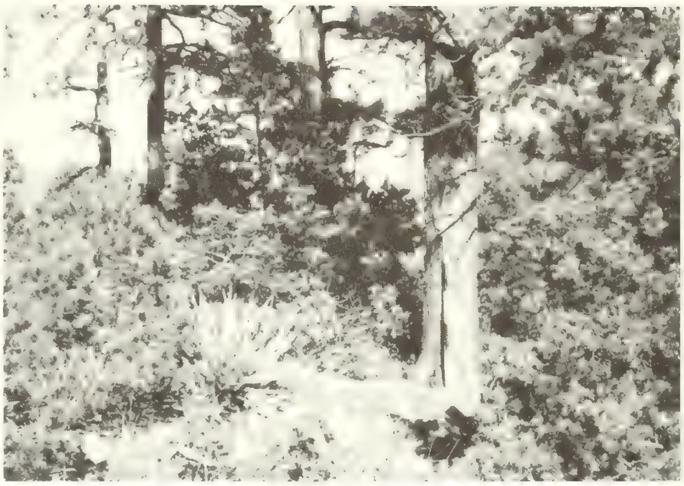

Figure 31.—*Pinus ponderosa/Quercus undulata* habitat type, Sangre de Cristo Mountains. In addition to *Q. undulata, Pinus edulis* and *Juniperus scopulorum* are important in this plot.

Adjacent habitat types.—On rocky slopes, the PIPO/BOGR HT merges with the PIPO/QUGA or PIPO/QUUN HT's. Pinyon-juniper woodland forms the lower ecotone with this habitat type. The type occurs near the xeric limit of *Pinus ponderosa* growth.

Comments.—This moderately extensive habitat type characteristically supports open stands bordering on pinyon-juniper woodlands or sagebrush meadows. The high cover of grasses makes the habitat type valuable for grazing by domestic stock and wildlife. Site quality for *Pinus ponderosa* is generally low. Hanks et al. (1983) suggest that *Bouteloua gracilis* often gains dominance in xeric *Festuca arizonica* habitats that have been overgrazed. Therefore, care must be taken in identifying habitat types in dry, grassy *Pinus ponderosa* communities.

Pinus ponderosa/Quercus undulata habitat type (PIPO/QUUN; ponderosa pine/wavyleaf oak)

This type is most common in northern New Mexico on the eastern foothills of the Sangre de Cristo Mountains, and is rare in Colorado and in the San Juan Mountains of New Mexico.

Vegetation.—*Pinus ponderosa* is the indicated climax in this habitat type, with *P. edulis* and *Juniperus scopulorum* frequently codominants. Undergrowths are characterized by an assortment of warm-dry indicators (fig. 31). *Quercus undulata*, the dominant shrub, exhibits up to 65% cover, but *Yucca* also is usually present. Other than *Artemisia ludoviciana*, forb cover is generally less than 1%, but various species of *Echinocereus* and *Opuntia* generally are found in the undergrowth. *Bouteloua gracilis, Muhlenbergia montana*, and *Schizachyrium scoparium* are dominant grasses and *Andropogon gerardi* is typically present.

Physical setting.—This habitat type occurs on mesa tops with lithic, sandy to loamy soils, and on canyon slopes with typically shallow coarse to fine textured soils. Elevations range from 6,550 to 8,200 feet (2,000 to 2,500 m). The type occurs on all aspects; surface rock cover is generally high, averaging 27%.

Adjacent habitat types.—The PIPO/QUUN HT has close similarity to two New Mexico habitat types: *Pinus ponderosa/Quercus grisea* defined in the Mogollon Mountains (Fitzhugh et al.[9]) and *Pinus ponderosa/Quercus undulata* of the Sacramento Mountains (Alexander et al. 1984). In northern New Mexico, the PIPO/QUUN HT shares close affinities with the PIPO/QUGA HT and intergrades at the hot, dry limits of the latter; both habitat types are characterized by a rich complement of grasses. On a single 4,037 square foot (375 m^2) plot, for example, 10 to 15 grasses may be encountered. On hotter and drier sites, this habitat type adjoins pinyon-juniper woodlands.

Comments.—*Quercus undulata* occupies sites at the hot and dry limits of *Q. gambelii*. Individuals with coriaceous leaves lacking distinct lobes were considered *Q. undulata*, while thin, lobed leaved individuals were classed as *Q. gambelii*. The two sites in which these oak variants occur seem to be intrinsically different and worthy of distinction into separate habitat types. Of those sites where *Quercus* is important, the PIPO/QUUN HT represents the hot, dry extreme.

Because of the environmental rigors of this habitat type, site potential for timber production is very low. Livestock grazing in this habitat type is faced with the same difficulties as discussed in the PIPO/QUGA HT, that is, general unavailability of surface water, impenetrable oak thickets, and typically low forage production.

Pinus ponderosa/Artemisia arbuscula habitat type (PIPO/ARAR; ponderosa pine/dwarf sage)

This minor habitat type is found in the vicinity of Petaca Peak in the San Juan Mountains of New Mexico.

Vegetation.— *Pinus ponderosa* is widely scattered among *P. edulis* and *Juniperus scopulorum*. Regeneration of *P. ponderosa* is light but sufficient to maintain climax populations. *P. edulis* and *J. scopulorum* regeneration is often dense. The shrub layer is dominated by *Artemisia arbuscula* ssp. *nova*, with lesser coverage of *Cercocarpus montanus Quercus gambelii, Ribes cereum, Symphoricarpos oreophilus*, and *Yucca glauca* (fig. 32).

Characteristic graminoids include *Carex heliophila, Koeleria macrantha, Muhlenbergia montana*, and *Sitanion hystrix*. Total herb cover is typically far less than shrub cover.

Physical setting.—This habitat type occurs on flat basalt mesa tops at elevations around 8,200 feet (2,500 m). Soils are mostly Typic Argiborolls with inclusions of Typic Eutroboralfs.

Adjacent habitat types.—On slightly drier sites the PIPO/ARAR HT adjoins pinyon-juniper woodlands, while slightly moister sites support the PIPO/QUGA HT, PIED phase.

Comments.—This minor type is of interest because of the Great Basin elements of its flora. Grazing capacity is minor and fuelwood opportunities are limited by difficult access.

This habitat type has not been previously described.

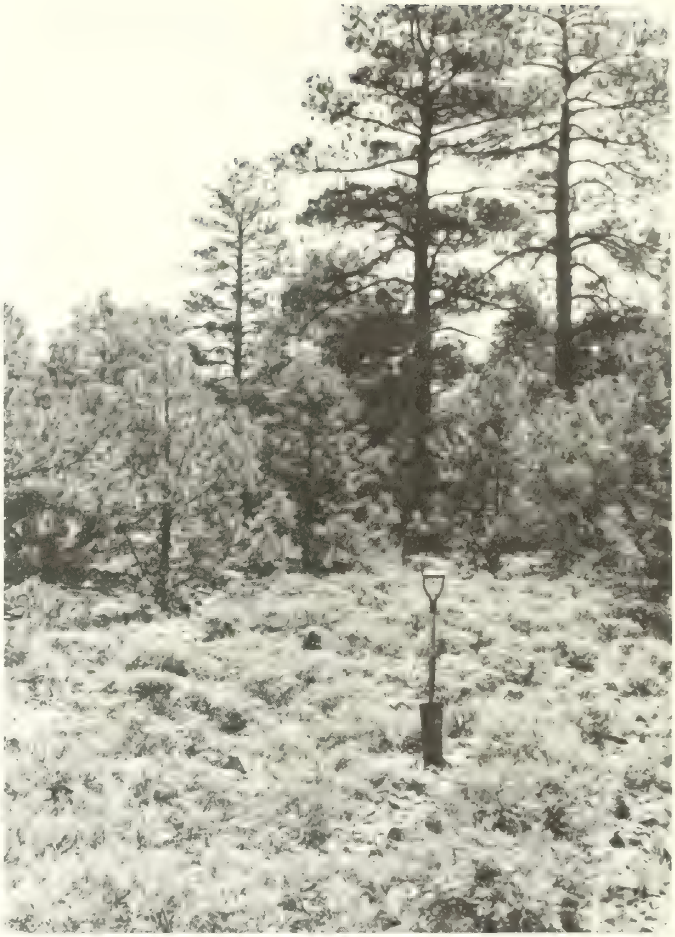

Figure 32.—*Pinus ponderosa/Artemisia arbuscula* habitat type, San Juan Mountains. Note the conspicuous ground layer of *A. arbuscula* ssp. *nova* and the strong dominance of *Pinus edulis* and *Juniperus scopulorum*.

Pinus ponderosa/Orysopsis hymenoides habitat type (PIPO/ORHY; ponderosa pine/indian ricegrass)

This minor type occurs on stabilized sand dunes in the vicinity of Espanola, N. Mex., and on the eastern edge of the Great Sand Dunes in Colorado.

Vegetation.—*Pinus ponderosa* and *Juniperus monosperma* typify the very open stands. Undergrowth species occurring in this type are characteristic of the warmest and driest of forested habitats. They include a shrub, *Poliomintha incana*, and two grasses—*Oryzopsis hymenoides* and *Shizachyrium scoparium*.

Physical setting.—The one plot sampled was at 5,900 feet (1,800 m) elevation on a dry, westerly exposure of a stabilized dune.

Adjacent habitat types.—Where vegetation has not yet gained a foothold the type forms ecotones with active sand dunes, while less sandy environments support *Pinus ponderosa/Quercus undulata* associations or pinyon-juniper woodlands.

Comments.—This type is of little consequence for management because of its rare occurrence. Berry (1963) described similar *Pinus ponderosa* forests occupying sandy soils at the forest-steppe ecotone in central Oregon.

OTHER HABITAT TYPES

Scree Forests

Scree habitat types occur throughout the study area.

Vegetation.—Scree habitat types occur in the *Pinus aristata, Picea engelmannii, Abies lasiocarpa, Abies concolor, Pseudotsuga menziesii*, and *Pinus ponderosa* series. *Pinus flexilis* is often important in the ABCO/HODU and PSME/HODU HT's. The undergrowth is sparse and species of high constancy generally do not occur in scree habitat types (fig. 33). Typically, shrubs are the dominant undergrowth vegetation.

Scree habitat types and their identifying characteristics are as follows:

1. The *Pinus aristata/Ribes montigenum* habitat type (PIAR/RIMO HT) is characterized by *Ribes montigenum* and *Saxifraga bronchialis*.
2. *Juniperus communis* and *Saxifraga bronchialis* are diagnostic in the *Picea engelmannii/Saxifraga bronchialis* habitat type (PIEN/SABR HT) and the *Abies lasiocarpa/Saxifraga bronchialis* habitat type (ABLA/SABR HT).
3. *Holodiscus dumosus, Jamesia americana*, and *Ribes* spp. are often important in the *Abies concolor/Holodiscus dumosus* habitat type (ABCO/HODU HT) and the *Pseudotsuga menziesii/Holodiscus dumosus* habitat type (PSME/HODU HT).
4. In the *Pinus ponderosa/Ribes inerme* habitat type (PIPO/RIIN HT), *Quercus gambelii* and *Ribes* spp. characterize the undergrowth.

Physical setting.—All scree habitat types are found on steep slopes of any exposure. Elevations range from 8,050 feet (2,450 m) in the PIPO/RIIN HT to 11,800 feet (3,600 m) in the PIEN/SABR HT. Mineral soil is confined to pockets between coarse rock fragments that typically compose greater than 80% of the substrate. Vegetation reaches a quasi-equilibrium with the shifting substrate (Pfister et al. 1977).

Adjacent habitat types.—Since scree may occur across the entire elevational gradient in any mountainous area with unstable substrate, any habitat type may adjoin scree.

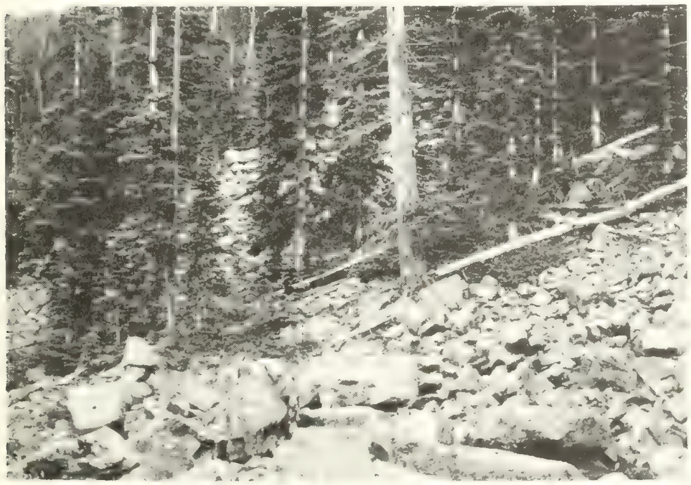

Figure 33.—Scree forest in the Sangre de Cristo Mountains. Shown here is the *Abies lasiocarpa/Saxifraga bronchialis* habitat type.

Comments.—Scree habitat types are more widespread than the small sample size of 19 plots suggests. Forest management opportunities are limited on these areas of poor site quality. Scree habitat types are of little value for grazing or timber production. Watershed and wildlife use generally are the only sustained-yield management options available for scree habitat types.

Scree habitat types are recognizable throughout the Rocky Mountain system. In Arizona and New Mexico, Fitzhugh et al.[9] recognized *Abies lasiocarpa/Holodiscus dumosus* (Scree), *Abies concolor/Jamesia americana* (Scree), and *Pseudotsuga menziesii/Holodiscus dumosus* (Scree) habitat types. Shepherd[6] described many stands identifiable as scree habitat types in south-central Colorado. Pfister et al. (1977) described scree forests in Montana but did not recognize habitat types.

Riparian Forests

Everywhere that streams are found within the study area, riparian habitat types are to be expected.

Vegetation.—Four series and five habitat types are recognized in riparian settings in the study area. These habitat types are:

1. The *Picea engelmannii/Heracleum sphondylium* habitat type (PIEN/HESP HT) is characterized by *Lonicera involucrata, Bromopsis ciliata, Erigeron eximius, Geranium richardsonii, Heracleum sphondylium, Mertensia ciliata, Osmorhiza depauperata, Thalictrum fendleri*, and *Viola canadensis* in the undergrowth.
2. The *Picea pungens/Swida sericea* habitat type (PIPU/SWSE HT) is characterized by *Swida sericea, Galium triflorum, Geranium richardsonii*, and *Smilacina stellata* in the undergrowth.
3. The *Picea pungens/Poa pratensis* habitat type (PIPU/POPR HT) consists of diagnostic *Poa pratensis* in the undergrowth.
4. The *Abies concolor/Galium triflorum* habitat type (ABCO/GATR HT) is characterized by *Acer glabrum, Prunus virginiana, Quercus gambelii, Poa pratensis, Galium triflorum*, and *Thalictrum fendleri* in the undergrowth.
5. The *Pinus ponderosa/Poa pratensis* habitat type (PIPO/POPR HT) consists of diagnostic *Poa pratensis* in the undergrowth.

Populus angustifolia generally is the dominant broadleaved tree. However, *Acer negundo* is often important in the PIPO/POPR HT while *Alnus tenuifolia* is a dominant in many stands in the other four habitat types. In excess of 50 species of undergrowth plants is not uncommon within a single, 4,037 square foot (375 m^2) plot in this type (fig. 34).

Physical setting.—Riparian habitat types are confined to stream floodplains at elevations ranging from 6,100 feet (1,860 m) in the PIPO/POPR HT to 9,050 feet (2,760 m) in the PIEN/HESP HT. Slopes are gentle to flat. Soils vary from Typic Udifluvents or Cryofluvents to Fluventic Haploborolls.

Adjacent habitat types.—Riparian forests adjoin these other herb-rich habitat types. Depending on elevation, these habitat-types may include ABCO/ACGL, PIPU/EREX, or ABLA/EREX.

Comments.—Since riparian habitat types occur on heavily utilized streamsides, few representative stands of the potential climax are available for sampling. Overgrazing has been pervasive and many sites have been converted from species-rich to species-poor sites dominated by *Poa pratensis*, an introduced grass capable of withstanding heavy grazing pressure. Because of the rarity of pristine riparian areas (only 23 plots were sampled), very little is known about riparian habitat types, which are widespread. Fluctuations in stream activity alters soil depth, depth to water table, and vegetation composition, thus adding to the difficulty in applying the climax concept to such sites (Steele et al. 1981). Further research may allow delineation of more habitat types within riparian forests.

Grazing potential is often high, not only because of high production of forbs and graminoids, but also because of the gentle topography and readily accessible water. Timber productivity is moderate within riparian habitat types. However, timber harvesting may be constrained by high water tables in some cases.

In the northern Rockies, Pfister et al. (1977) and Steele et al. (1981) recognizd bottomland hardwood forests and floodplain communities, and Daubenmire and Daubenmire (1968) described *Populus trichocarpa* forests that are representative of the riparian forests identified here. Other investigators have recognized streamside habitat types within a *Picea pungens* series (Fitzhugh et al.,[9] Hess and Wasser,[8] Moir and Ludwig 1979), within a *Abies concolor* series (Alexander et al. 1984, Fitzhugh et al.[9]), and within a *Populus angustifolia* series (Fitzhugh et al.[9]).

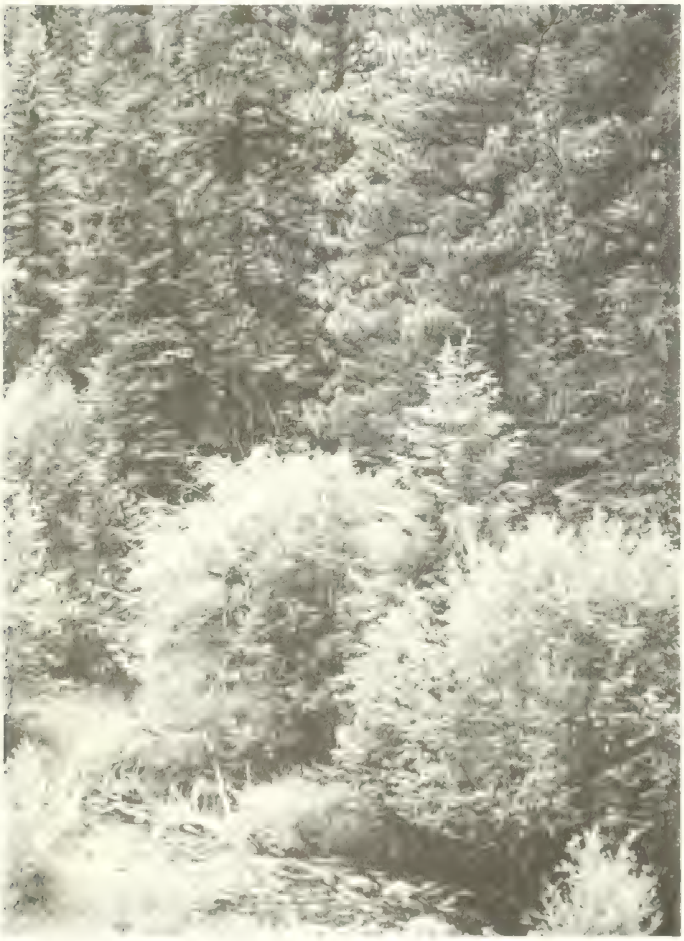

Figure 34.—Riparian forest in the San Juan Mountains. This plot in the *Picea pungens/Swida sericea* habitat type contains 50 vascular plant species in the undergrowth with a total cover in excess of 100%.

SUMMARY

This classification study of forest habitat types in the mountains of northern New Mexico and southern Colorado identified 2 habitat types in the *Pinus aristata* series, 8 habitat types and 2 phases in the *Picea engelmannii* and *Abies lasiocarpa* series, 15 habitat types and 2 phases in the 4 mixed conifer series, and 8 habitat types and 8 phases in the *Pinus ponderosa* series. In addition, 6 forested scree and 5 riparian habitat types were sampled. Thus, a total of 8 climax series, 44 habitat types, and 12 phases of habitat types are defined.

Successional trends varied widely among habitat types. In the *Picea engelmannii* and *Abies lasiocarpa* series, succession to *P. engelmannii* and *A. lasiocarpa* is direct in the highest and coldest elevations, while lower elevations may exhibit any, or a combination, of *Populus tremuloides*, *Abies concolor*, and *Pseudotsuga menziesii* as major seral trees. Succession within the mixed conifer series features *Populus tremuloides*, *Pinus flexilis*, *Pinus ponderosa*, and *Quercus gambelii* as major seral trees. *Q. gambelii* is the principal seral tree of the *Pinus ponderosa* series. More moist habitat types in the *P. ponderosa* series may be regarded as fire climaxes since in the absence of fire the more shade-tolerant, but less fire-resistant *Abies concolor* and *Pseudotsuga menziesii* may eventually dominate.

Close vegetational relationships exist among the many forest habitat types described throughout the Rocky Mountains. The most striking similarities occur within the *Picea engelmannii* and *Abies lasiocarpa* series, while habitat types in the mixed conifer and *Pinus ponderosa* series are of relatively localized occurrence.

Considerable soil variation occurs among the habitat types described. Soil orders sampled in the study included Alfisols, Entisols, Inceptisols, and Mollisols. Soil moisture and soil temperature regimes varied from udic-cryic in the *Picea engelmannii* and *Abies lasiocarpa* series to ustic-frigid in the *Pinus ponderosa* series.

Field identification of habitat types is accomplished through use of a dichotomous key. Ideally, since the classification was developed using mature, minimally disturbed forest, identification of habitat type using the keys and descriptions given is best achieved through examining near-pristine vegetation.

Although this study does not profess to describe all the forest habitat types of northern New Mexico and southern Colorado, it is still quite comprehensive. Furthermore, refinement of the classification should be forthcoming following field evaluation of keys and descriptions.

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APPENDIX 1

Plant List of All Species Identified in Study

Yng regen = trees less than 2 inches (5 cm) d.b.h.
Adv regen = trees 2-10 inches (5-25 cm) d.b.h.
Mature = trees larger than 10 inches (25 cm) d.b.h.

Species	No. of times observed
Trees	
Abies concolor	
Yng regen	185
Adv regen	170
Mature	125
Abies lasiocarpa	
Yng regen	236
Adv regen	223
Mature	169
Acer negundo	
Yng regen	2
Adv regen	2
Mature	2
Juniperus monosperma	
Yng regen	45
Adv regen	19
Mature	4
Juniperus osteosperma (*J. utahensis*)	
Yng regen	2
Adv regen	3
Mature	0
Juniperus scopulorum	
Yng regen	87
Adv regen	61
Mature	18
Picea engelmannii	
Yng regen	250
Adv regen	254
Mature	231
Picea pungens	
Yng regen	87
Adv regen	88
Mature	66
Pinus aristata	
Yng regen	19
Adv regen	18
Mature	16
Pinus contorta	
Yng regen	3
Adv regen	5
Mature	3
Pinus edulis	
Yng regen	105
Adv regen	67
Mature	10
Pinus flexilis	
Yng regen	103
Adv regen	77
Mature	49
Pinus ponderosa	
Yng regen	204
Adv regen	232
Mature	265
Populus angustifolia	
Yng regen	8
Adv regen	8
Mature	14
Populus tremuloides	
Yng regen	113
Adv regen	129
Mature	46
Pseudotsuga menziesii	
Yng regen	270
Adv regen	267
Mature	245
Shrubs	
Acer glabrum	104
Alnus spp.	10
Alnus tenuifolia	8
Amelanchier alnifolia	108
Amelanchier goldmannii	1
Amelanchier utahensis	15
Amorpha canescens	15
Arctostaphylos uva-ursi	95
Artemisia arbuscula ssp. *nova*	6
Artemisia tridentata	8
Berberis fendleri	23
Ceanothus fendleri	40
Cercocarpus montanus	99
Chimaphila umbellata	12
Chrysothamnus spp.	2
Chrysothamnus depressus	6
Chrysothamnus greenei	3
Chrysothamnus nauseosus	27
Chrysothamnus viscidiflorus	3
Clematis columbiana (*C. pseudoalpina*)	115
Clematis hirsutissima	10
Clematis ligusticifolia	7
Fallugia paradoxa	3
Fendlera rupicola	1
Forestiera neomexicana	4
Fraxinus anomala	2
Gaultheria humifusa	1
Holodiscus dumosus	31
Jamesia americana	48
Juniperus communis	189
Linnaea borealis	55
Lonicera involucrata	151
Mahonia repens (*Berberis repens*)	181
Nolina microcarpa	3
Pachistima myrsinites	205
Pentaphylloides floribunda (*Potentilla fruticosa*)	13
Philadelphus spp.	1
Physocarpus monogynus	26
Poliomintha incana	1

Prunus spp.	1
Prunus virginiana	67
Purshia tridentata	11
Quercus gambelii	201
Quercus gambelii (*Q. gambelii* x *Q. undulata*)	26
Quercus undulata (*Q. gambelii* x *Q. grisea*)	16
Quercus undulata (*Q. undulata* x *Q. grisea*)	9
Rhus aromatica (*R. trilobata*)	33
Ribes spp.	3
Ribes cereum	70
Ribes inerme	48
Ribes montigenum	129
Ribes pinetorum	3
Ribes viscosissimum	1
Ribes wolfii	68
Robinia neomexicana	20
Rosa spp. (Predominantly *R. woodsii* *R. fendleri*)	265
Rubus deliciosus	5
Rubus neomexicanus	2
Rubus parviflorus	108
Rubus idaeus var. *strigosus* (*R. strigosus*)	41
Salix spp.	25
Salix depressa (*S. bebbiana*)	1
Salix scouleriana	47
Salix subcoerulea	1
Sambucus spp.	13
Sambucus racemosa	33
Shepherdia canadensis	88
Sorbus spp.	8
Sorbus scopulina	9
Swida sericea (*Cornus stolonifera*)	30
Symphoricarpos oreophilus	241
Toxicodendron rydbergii (*Rhus radicans*)	13
Vaccinium caespitosum (*V. cespitosum*)	7
Vaccinium myrtillus (*V. oreophilum*)	221
Xanthocephalum sarothrae (*Gutierrezia sarothrae*)	30
Yucca baccata	17
Yucca glauca	28

Graminoids

Agropyron spp.	9
Agropyron desertorum	1
Agropyron elongatum	2
Agropyron smithii	16
Agropyron subsecundum	10
Agropyron trachycaulum	19
Agrostis spp.	4
Agrostis gigantea (*A. alba*)	8
Agrostis scabra	17
Andropogon gerardi	34
Aristida spp.	1
Aristida arizonica	10
Aristida fendleriana	19
Aristida longiseta	8
Blepharoneuron tricholepis	64
Bouteloua curtipendula	29
Bouteloua gracilis	72
Bouteloua hirsuta	6
Bromopsis ciliata (*Bromus ciliatus*)	334
Bromopsis lanatipes (*Bromus lanatipes*)	23
Bromopsis porteri (*Bromus anomalous*)	5
Bromus spp.	16
Bromus polyanthus	2
Bromus tectorum	5
Calamagrostis canadensis	19
Calamagrostis inexpansa	2
Calamagrostis purpurascens	1
Carex spp.	100
Carex aurea	1
Carex bella	17
Carex brevipes	4
Carex deweyana	3
Carex ebenea	2
Carex elynoides	2
Carex festivella	1
Carex foenea	86
Carex geophila	5
Carex geyeri	49
Carex heliophila	31
Carex lanuginosa	1
Carex microptera	11
Carex norvegica ssp. *stevenii* (*C. media*)	2
Carex nova	1
Carex occidentalis	13
Carex praegracilis	2
Carex rossii	277
Carex rupestris	1
Carex scopulorum	1
Carex stenophylla ssp. *eleocharis* (*C. eleocharis*)	1
Carex utriculata (*C. rostrata*)	2
Carex vallicola	1
Cyperus fendlerianus	1
Danthonia intermedia	2
Danthonia parryi	38
Deschampsia caespitosa	13
Dichanthelium lanuginosum (*Panicum huachucae*)	4
Elymus spp.	7
Elymus ambiguus	1
Elymus canadensis	3
Elymus glaucus	31
Eragrostis spp.	1
Eragrostis intermedia	1
Festuca arizonica	154

Festuca brachyphylla (*F. ovina* ssp. *brachyphylla*)	22
Festuca sororia	28
Festuca thurberi	48
Glyceria elata	1
Glyceria striata	4
Hilaria jamesii	1
Juncus arcticus (*J. balticus*)	3
Juncus drummondii	1
Juncus longistylis	2
Juncus parryi	3
Koeleria macrantha (*K. cristata*)	260
Leucopoa kingii	1
Luzula parviflora	75
Luzula spicata	1
Lycurus phleoides	5
Mariscus schweinitzii (*Cyperus schweinitzii*)	2
Melica porteri	7
Muhlenbergia spp.	3
Muhlenbergia emersleyi	1
Muhlenbergia montana	191
Muhlenbergia monticola	2
Muhlenbergia pungens	1
Muhlenbergia racemosa	3
Muhlenbergia rigens	3
Muhlenbergia virescens	2
Muhlenbergia wrightii	1
Oryzopsis spp.	12
Oryzopsis asperifolia	52
Oryzopsis hymenoides	15
Oryzopsis micrantha	21
Panicum spp.	1
Panicum obtusum	1
Panicum virgatum	3
Phleum commutatum (*P. alpinum*)	7
Phleum pratensis	7
Piptochaetium fimbriatum	1
Poa spp.	7
Poa alpina	6
Poa arctica ssp. *grayana*	1
Poa compressa	2
Poa epilis	1
Poa fendleriana	308
Poa glauca var. *rupicola* (*P. rupicola*)	3
Poa leptocoma	13
Poa nemoralis var. *interior* (*P. interior*)	18
Poa nervosa var. *tracyi*	1
Poa palustris	1
Poa pratensis	78
Poa reflexa	13
Schizachne purpurascens	5
Schizachyrium scoparium (*Andropogon scoparius*)	72
Sitanion hystrix (*S. longifolium*)	216
Sorghastrum avenaceum (*S. nutans*)	16
Sporobolus cryptandrus	7
Sporobolus giganteus	1
Stipa spp.	10
Stipa comata	19
Stipa occidentalis (*S. columbiana*)	5
Stipa pringlei	2
Stipa robusta	1
Trisetum spicatum ssp. *montanum* (*T. montanum*)	148
Trisetum wolfii	2

Forbs

Abronia spp.	1
Achillea millefolium ssp. *lanulosa* (*A. lanulosa*)	187
Acomastylis rossii (*Geum rossii*)	8
Aconitum columbianum	11
Actaea rubra ssp. *arguta* (*A. arguta*)	65
Agastache pallidiflora	1
Ageratina herbacea (*Eupatorium herbaceum*)	8
Agoseris aurantiaca	6
Agoseris glauca	2
Agrimonia striata	3
Allium spp.	4
Allium cernuum	103
Allium geyeri	8
Ambrosia spp.	1
Androsace septentrionalis	63
Anemone spp.	1
Anemone canadensis	1
Angelica grayii	23
Antennaria spp.	38
Antennaria neglecta (*A. marginata*)	47
Antennaria parvifolia (*A. aprica*)	2
Antennaria rosea	169
Anticlea elegans (*Zygadenus elegans*)	75
Apocynum spp.	31
Apocynum androsaemifolium	19
Aquilegia spp.	13
Aquilegia caerulea	55
Aquilegia chrysantha	1
Aquilegia elegantula	81
Arabis spp.	65
Arabis drummondii	23
Arabis fendleri	57
Aralia spp.	1
Aralia nudicaulis	1
Arctium minus	1
Arenaria spp.	10
Arenaria fendleri	39
Arenaria lanuginosa (*A. confusa*, *A. saxosa*)	8

Arnica spp.	16
Arnica cordifolia	150
Arnica latifolia	5
Arnica mollis	10
Artemisia spp.	2
Artemisia campestris ssp. *pacifica* (*A. pacifica*)	4
Artemisia carruthii	52
Artemisia dracunculoides	17
Artemisia franserioides	139
Artemisia frigida	31
Artemisia ludoviciana	144
Artemisia parryi	1
Artemisia scopulorum	2
Asclepias spp.	1
Asclepias asperula (*A. capricorna*)	1
Asclepias tuberosa	1
Asclepias viridiflora	2
Asparagus officinalis	1
Aster spp.	9
Aster foliaceus	1
Aster glaucodes	7
Aster laevis	6
Astragalus spp.	4
Astragalus adsurgens	2
Astragalus drummondii	6
Astragalus flexuosus	8
Astragalus humistratus	1
Astragalus lonchocarpus	1
Astragalus parryi	1
Astragalus tenellus	1
Astragalus wingatanus	1
Bahia dissecta	34
Balsamorhiza sagittata	2
Batrachium trichopyllus (*Ranunculus trichophyllus*)	1
Besseya plantaginea	6
Bidens bipinnata	2
Bistorta bistortoides (*Polygonum bistortoides*)	11
Bistorta vivipara (*Polygonum viviparum*)	13
Brickellia spp.	15
Brickellia brachyphylla	2
Brickellia grandiflora	30
Brickellia microphylla (*B. scabra*)	1
Calochortus gunnisonii	7
Caltha leptosepala	16
Calypso bulbosa	19
Campanula rotundifolia	119
Cardamine cordifolia	24
Castilleja spp.	19
Castilleja integra	3
Castilleja linariaefolia	17
Castilleja lineata	8
Castilleja miniata	33
Castilleja occidentalis	2
Castilleja rhexifolia	6
Castilleja sulphurea	2
Cerastium spp.	2

Cerastium arvense	5
Chaenactis spp.	2
Chaenactis douglasii	6
Chamaepericlymenum canadense (*Cornus canadensis*)	1
Chamaesyce albomarginata (*Euphobia albomarginata*)	1
Chamaesyce fendleri (*Euphobia fendleri*)	2
Chamerion angustifolium (*Epilobium angustifolium*)	137
Cheilanthes spp.	6
Cheilanthes fendleri	7
Chenopodium spp.	8
Chenopodium aff album	12
Chenopodium fremontii	6
Chenopodium graveolens	2
Cicuta douglasii	2
Circaea alpina	2
Cirsium spp.	42
Cirsium canescens	1
Cirsium pallidum	1
Cirsium parryi	10
Cirsium scopulorum	2
Cirsium undulatum	1
Clementsia rhodantha (*Sedum rhodanthum*)	3
Coeloglossum viride (*Habenaria viridus*)	1
Comandra umbellata ssp. *pallida* (*C. pallida*)	31
Commelina dianthifolia	2
Conioselinum scopulorum	1
Conopholis mexicana	2
Conyza canadensis	1
Conyza schiedeana	1
Corallorhiza spp.	10
Corallorhiza maculata	51
Corallorhiza striata	11
Corallorhiza trifida	2
Coreopsis lanceolata	1
Corydalis aurea	1
Corydalis caseana	2
Coryphant spp.	2
Cosmos parviflora	2
Crepis spp.	2
Cryptantha jamesii	9
Cryptantha thyrsiflora	3
Cryptogramma crispa	2
Cynoglossum officinale	4
Cypripedium calceolus	1
Cystopteris fragilis	40
Dalea spp.	1
Dalea candida var. *oligophylla* (*Petalostemon candidus*)	4
Dalea purpurea (*Petalostemon purpurea*)	8
Delphinium spp.	1
Delphinium barbeyi	29
Descurainia spp.	2
Descurainia richardsonii	12
Disporum trachycarpum	29

Dithyrea wislizeni	1
Dodecatheon ellisiae	2
Dodecatheon pulchellum	1
Draba spp.	32
Draba aurea	26
Draba helleriana	33
Draba smithii	1
Draba spectabilis	2
Draba streptocarpa	19
Drymocallis fissa (*Potentilla fissa*)	10
Dryopteris filix-mas	1
Dugaldia hoopesii (*Helenium hoopsii*)	15
Echinocereus spp.	18
Echinocereus fendleri	1
Echinocereus viridiflorus	2
Epilobium spp.	19
Epilobium adenocaulon	3
Epilobium ciliatum (*E. glandulosum*)	3
Epilobium hornemannii	8
Equisetum spp.	5
Equisetum arvense	15
Erigeron spp.	17
Erigeron canus	1
Erigeron compositus	2
Erigeron concinnus	22
Erigeron coulteri	14
Erigeron divergens	5
Erigeron elatior	1
Erigeron eximius (*E. superbus*)	221
Erigeron flagellaris	95
Erigeron formosissimus	63
Erigeron melanocephalus	4
Erigeron peregrinus	32
Erigeron platyphyllus	1
Erigeron speciosus var. *speciosus*	25
Erigeron subtrinervis	72
Erigeron vetensis	10
Eriogonum alatum	46
Eriogonum annuum	1
Eriogonum bakeri	1
Eriogonum jamesii	38
Eriogonum microthecum	3
Eriogonum racemosum	38
Eriogonum umbellatum	7
Erysimum spp.	3
Erysimum asperum	4
Erysimum capitatum	52
Erythronium grandiflorum	8
Euphorbia spp.	2
Euphorbia robusta	5
Fragaria americana (*F. vesca* var. *bracteata*)	122
Fragaria ovalis (*F. virginiana* var. *glauca*)	302
Frasera speciosa (*Swertia radiata*)	38
Gaillardia aristata	1
Gaillardia pinnatifida	1
Galium spp.	5
Galium aparine	6
Galium boreale	56
Galium trifidum	45
Galium triflorum	52
Gaura spp.	2
Gaura neomexicana	1
Gayophytum diffusum (*G. nuttallii*)	1
Gentiana spp.	6
Gentianella amarella ssp. *acuta* (*Gentiana amarella, G. strictiflora*)	25
Gentianella amarella ssp. *heterosepala* (*Gentiana heterosepala*)	23
Geranium spp.	7
Geranium caespitosum (*G. fremontii*)	91
Geranium richardsonii	185
Geum aleppicum ssp. *strictum* (*G. strictum*)	3
Geum macrophyllum	3
Gilia spp.	2
Gilia pinnatifida var. *calcarea*	9
Gnaphalium spp.	4
Gnaphalium viscosum (*G. macounii*)	6
Gnaphalium wrightii	1
Goodyera oblongifolia	137
Goodyera repens	15
Habenaria spp.	5
Hackelia spp.	4
Hackelia floribunda	3
Harbouria trachypleura	19
Hedeoma drummondii	1
Helianthella parryi	46
Helianthella quinquenervis	2
Helianthus annuus	1
Heliomeris multiflora (*Viguiera multiflora*)	29
Heliopsis helianthoides (*H. scabra*)	1
Heracleum sphondylium (*H. lanatum*)	33
Herrickia horrida (*Aster horridus*)	2
Heterotheca fulcrata (*Chrysopsis villosa* var. *foliosa*)	123
Heuchera spp.	20
Heuchera parvifolia	9
Hieracium spp.	6
Hieracium fendleri	38
Hieracium geyeri	1
Hieracium gracile	9
Hippochaete hyemalis (*Equisetum hiemale*)	5
Hippochaete laevigata (*Equisetum laevigatum*)	2
Humulus lupulus	1
Hydrophyllum fendleri	17
Hymenopappus filifolius (*H. lugens*)	2

Hymenopappus radiatus	8
Hymenoxys spp.	5
Hymenoxys acaulis	43
Hymenoxys grandiflora	1
Hymenoxys ivesiana	4
Hymenoxys richardsonii	46
Hypericum formosum	1
Ipomoea coccinea	1
Ipomopsis aggregata (*Gilia aggregata*)	90
Iris missouriensis	23
Krascheninnikovia lanata (*Ceratoides lanata, Eurotia lanata*)	5
Kuhnia rosmarinifolia (*K. chlorolepis*)	1
Lactuca serriola (*L. scariola*)	2
Lappula spp.	1
Lappula redowskii	2
Lathyrus spp.	203
Lathyrus arizonicus x *graminifolius*	1
Lathyrus graminifolius	7
Leonurus cardiaca	1
Lepidium spp.	4
Lepidium virginicum	1
Leptodactylon pungens	1
Lesquerella sp.	1
Lesquerella alpina (*L. subumbellata*)	1
Lesquerella fendleri	14
Lesquerella montana	6
Leucanthemum vulgare (*Chrysanthemum leucanthemum*)	1
Leucelene ericoides	2
Liatrus punctata	17
Ligularia amplectens (*Senecio amplectens*)	39
Ligularia bigelovii (*Senecio bigelovii*)	11
Ligularia pudica (*Senecio pudicus*)	2
Ligusticum porteri	108
Limnorchis saccata (*Habenaria saccata*)	3
Linanthus nuttallii (*Linanthastrum nuttallii*)	1
Linum spp. (annuals)	4
Linum aristatum	1
Listera cordata	21
Lithospermum multiflorum	119
Lotus wrightii	32
Lupinus spp.	11
Lupinus argenteus	39
Lupinus kingii	4
Macromeria viridiflora	2
Mammalaria spp.	12
Medicago lupulina	1
Melampodium cinereum	2
Melilotus alba	2
Melilotus officinalis	3
Mentha arvensis	8
Mentzelia pumila	2
Mertensia spp.	7
Mertensia ciliata	96
Mertensia franciscana	24
Mertensia lanceolata	36
Mertensia viridi	3
Mimulus guttatus	4
Mitella pentandra	24
Moehringia macrophylla (*Arenaria macrophylla*)	7
Monarda fistulosa var. *menthaefolia* (*M. menthaefolia*)	4
Moneses uniflora (*Pyrola uniflora*)	75
Monotropa latisquama	6
Oenothera caespitosa	9
Oenothera coronopifolia	4
Oenothera villosa (*O. strigosa*)	1
Opuntia spp. (Prickly pears)	1
Opuntia engelmannii	16
Opuntia imbricata	3
Opuntia polyacantha	24
Oreochrysum parryi (*Haplopappus parryi*)	252
Oreoxis alpina	3
Oreoxis bakeri	3
Orobanche sp.	1
Orobanche fasciculata	1
Orthilia secunda (*Pyrola secunda,* *Ramischia secunda*)	224
Orthocarpus luteus	1
Orthocarpus purpureo-albus	2
Osmorhiza chilensis	3
Osmorhiza depauperata (*O. obtusa*)	181
Oxalis spp.	7
Oxalis violaceae	5
Oxybaphus linearis (*Mirabilis linearis*)	14
Oxypolis fendleri	28
Oxytropis spp.	3
Oxytropis lambertii	7
Oxytropis sericea	1
Parnassia fimbriata	2
Parthenocissus spp.	3
Pedicularis spp.	1
Pedicularis bracteosa	11
Pedicularis canadensis	2
Pedicularis grayii	37
Pedicularis groenlandica	1
Pedicularis parryi	1
Pedicularis racemosa	96
Pennellia micrantha	1
Penstemon spp.	2
Penstemon barbatus	107
Penstemon bridgesii	7
Penstemon griffinii (*P. oliganthus*)	23
Penstemon linarioides	37

Penstemon virens	8
Penstemon virgatus	34
Penstemon whippleanus	24
Petasites sagittata	4
Phacelia spp.	7
Phacelia heterophylla	15
Phacelia ivesiana	2
Phacelia neomexicana	1
Phlox spp.	2
Phlox condensata (*P. caespitosa*)	3
Phlox nana	5
Physalis virginiana var. *sonorae* (*P. longiflora*)	2
Physaria acutifolia (*P. australis*)	1
Piperia unalascensis (*Habenaria unalascensis*)	1
Plantago major	1
Pneumonanthe calycosa (*Gentiana parryi*)	4
Polemonium spp.	1
Polemonium foliosissimum	3
Polemonium pulcherrimum ssp. *delicatum* (*P. delicatum*)	79
Polemonium viscosum	1
Polygala spp.	1
Polygonum sawatchensis	60
Potentilla spp.	5
Potentilla anserina	1
Potentilla concinna	2
Potentilla crinita	8
Potentilla diversifolia	7
Potentilla gracilis var. *pulcherrima*	56
Potentilla hippiana	92
Potentilla norvegica	1
Potentilla pennsylvanica	6
Primula parryi	7
Prunella vulgaris	7
Pseudocymopteris montanus	249
Pseudostellaria jamesiana (*Stellaria jamesiana*)	22
Psoralea tenuiflora	5
Pteridium aquilinum	10
Pterospora andromeda	34
Pulsatilla patens	35
Pyrola asarifolia	29
Pyrola chlorantha (*P. virens*)	70
Pyrola minor	4
Pyrola picta	11
Ranunculus spp.	4
Ranunculus alismaefolius	2
Ranunculus cardiophyllus	1
Ranunculus eschscholtzii	7
Ranunculus inamoenus	2
Ranunculus macounnii	2
Ranunculus uncinatus	2
Ratibida columnaris	2
Rhodiola integrifolia (*Sedum rosea*)	14
Rudbeckia hirta	6
Rudbeckia laciniata	14
Rumex crispus	1
Saxifraga spp.	3
Saxifraga bronchialis	51
Saxifraga odontoloma	9
Saxifraga rhomboidea	6
Scutellaria spp.	1
Sedum spp.	6
Sedum cockerellii	2
Sedum lanceolatum (*S. stenopetalum*)	26
Senecio spp.	5
Senecio atratus	10
Senecio crocatus	1
Senecio dimorphophyllus	1
Senecio eremophilus	22
Senecio fendleri	110
Senecio hartianus	1
Senecio integerrimus	2
Senecio neomexicanus	91
Senecio neomexicanus var. *mutabilis* (*S. mutabilis*)	2
Senecio sanguisorboides	13
Senecio serra	10
Senecio streptanthifolius (*S. cymbalarioides*)	28
Senecio triangularis	16
Senecio wootoni	62
Sibbaldia procumberns	14
Sidalcea neomexicana	6
Silene spp.	4
Silene acaulis	2
Silene antirrhina	1
Silene laciniata	1
Silene menziesii	21
Silene scouleri	39
Sisymbrium spp.	1
Smilacina racemosa	126
Smilacina stellata	130
Solidago spp.	56
Solidago canadensis	3
Solidago missouriensis	10
Solidago missouriensis var. *extraria*	1
Solidago nana	3
Solidago sparsiflora	23
Solidago spathulata var. *neomexicana* (*S. decumbens*)	39
Solidago spathulata var. *nana*	1
Solidago wrightii	3
Sphaeralcea coccinea	1
Stachys coccinea	2
Stachys palustris	3
Stellaria spp.	10
Stellaria laeta (*S. longipes*)	16
Stellaria umbellata	10
Stephanomeria exigua	1
Streptanthus spp.	1
Streptopus amplexifolius	45
Swertia perennis	2
Taraxacum spp.	1

Taraxacum officinale	97
Tetradymia canescens	1
Teucrium spp.	1
Thalictrum fendleri	181
Thelesperma filifolium	2
Thelesperma magapotamicum	5
Thelypodiopsis linearifolia	12
Thermopsis spp.	57
Thlaspi spp.	5
Thlaspi arvense	3
Thlaspi montanum var. *montanum* (*T. fendleri*)	64
Townsendia spp.	2
Townsendia eximia	9
Townsendia formosa	2
Tradescantia occidentalis	1
Tragia ramosa	4
Tragopogon spp.	13
Tragopogon dubius	3
Trautvetteria carolinensis (*T. grandis*)	12
Trifolium spp.	15
Trifolium brandegei	4
Trifolium dasyphyllum	9
Trifolium dubium	1
Trifolium parryi	1
Trifolium wormskjoldii	1
Trollius laxis	11
Urtica spp.	7
Urtica dioica	3
Valeriana spp.	3
Valeriana capitata ssp. *acutiloba*	16
Valeriana edulis	7
Veratrum californicum	16
Verbascum thapsus	10
Veronica spp.	3
Veronica americana	1
Veronica serphyllifolia	1
Veronica wormskjoldii	14
Vicia americana	137
Vicia ludoviciana var. *texana* (*V. exigua*)	2
Vicia pulchella	1
Viguiera spp.	2
Viola spp.	2
Viola adunca	37
Viola canadensis	157
Viola nephrophylla	7
Woodsia ssp.	5
Woodsia oregana	2
Wyethia amplexicaulis	4
Wyethia arizonica	6
Zygadenus ssp.	38

APPENDIX 2

Keys to the Forest Series and Habitat Types of Northern New Mexico and Southern Colorado

Before attempting to apply keys for field identification, familiarization with the following guidelines is necessary.

1. Locate that portion of the stand that, in your judgment, best represents the typical vegetation of the stand. The tree canopy should be mature and the undergrowth should not be severely disturbed. Extrapolation from the nearest mature stand occupying a similar site may be necessary in some areas of widespread disturbance.
2. Note mature trees and their reproduction, by species, within the stand. Particular attention must be given to tree reproduction; reference to trees in the key primarily concerns regeneration since habitat types are based on potential climax, not necessarily current conditions.
3. Accurately identify and estimate cover of dominant shrub and herb species within the stand and note presence of indicator species given in the key that may have minor cover in the stand to be sampled. Careful comparisons of the descriptive material and the vegetation being investigated will usually allow identification of the correct habitat type even in the absence of a species used in the habitat type name.
4. Note the physical setting of the stand, including elevation, aspect, percent slope, landform, and soil depth and coarse fragments.
5. Identify the habitat type by following the key.
6. If difficulty arises in habitat type identification, compare the stand with the synoptic descriptions and species frequency and cover tables given for the series and types in question and decide which best fits the stand characteristics.
7. If it becomes apparent that an undescribed habitat type has been found, the stand should be measured thoroughly or its precise location given to the USDA Forest Service Regional Ecologist.
8. The following canopy coverage terms are used in the keys. In stands where dense shading or heavy duff accumulation has resulted in an unusually sparse undergrowth, adjust definitions to the next lower coverage class:
   (1) "scarce" = less than 1% cover, versus "common" = greater than 1% cover;
   (2) "poorly represented" = less than 5% cover, versus "well represented" = greater than 5% cover;
   (3) "abundant" = greater than 25% cover.

Forest Series Key

1. Forests of talus or debris slopes with fragmental soils (cobbles and stones greater than 90% soil volume) and poorly developed undergrowths ———————————————— Scree Forests
1. Forests on other sites with relatively well-developed undergrowths (although some sites may be rocky) ———————————————— 2
2. Forests of streamsides with *Populus angustifolia* and/or *Alnus tenuifolia* generally present ———————————————— Riparian Forests
2. Forests of canyons, sideslopes, and ridges; sometimes of bottoms, protected benches, or seeps, but then *Populus angustifolia* and *Alnus tenuifolia* both absent ———————————————— 3
3. *Pinus aristata* or *P. flexilis* well represented and reproducing successfully, usually dominant in open stands ——— *Pinus aristata* and *Pinus flexilis* Series
3. *Pinus aristata* and *P. flexilis* both poorly represented or absent ———————————————— 4
4. *Abies lasiocarpa* and/or *Picea engelmannii* present and reproducing successfully, dominant over regeneration of *Abies concolor* and *Pseudotsuga menziesii* (if either are present) ———————— *Picea engelmannii* and *Abies lasiocarpa* Series
4. *Abies lasiocarpa* and/or *Picea engelmannii* not the indicated climax, if present, minor in regeneration relative to other conifers ———————— 5
5. *Picea pungens*, *Abies concolor*, and/or *Pseudotsuga menziesii* present and reproducing successfully, not accidental ——— *Picea pungens*, *Abies concolor*, or *Pseudotsuga menziesii* Series
5. *Picea pungens*, *Abies concolor*, and/or *Pseudotsuga menziesii* not the indicated climax, but may be accidental ———————— *Pinus ponderosa* Series

Scree Forests

1. *Picea engelmannii* and/or *Abies lasiocarpa* present and reproducing successfully ———————— 2
1. *Picea engelmannii* and/or *Abies lasiocarpa* not the indicated climax ———————— 3
2. *Picea engelmannii* dominant ——— PIEN/SABR HT
2. *Picea engelmannii* scarce or absent ———————— ABLA/SABR HT
3. *Abies concolor* and/or *Pseudotsuga menziesii* present and reproducing successfully ———————— 4
3. *Abies concolor* and/or *Pseudotsuga menziesii* not the indicated climax ———————— 5
4. *Abies concolor* dominant ——— ABCO/HODU HT
4. *Abies concolor* scarce or absent ———————— PSME/HODU HT
5. *Pinus aristata* present ———— PIAR/RIMO HT
5. *Pinus aristata* absent ———— PIPO/RIIN HT

Riparian Forests

1. *Picea engelmannii* present and reproducing successfully ———————— PIEN/HESP HT
1. *Picea engelmannii* not the indicated climax ——— 2
2. *Picea pungens* and/or *Abies concolor* present and reproducing successfully ———————— 3
2. *Picea pungens* or *Abies concolor* not the indicated climax ———————— PIPO/POPR HT
3. *Picea pungens* present ———————— 4
3. *Picea pungens* absent ———— ABCO/GATR HT
4. *Swida sericea* present ———— PIPU/SWSE HT
4. *Swida sericea* absent ———— PIPU/POPR HT

Pinus aristata and *Pinus flexilis* Series

1. *Pinus aristata* well represented and reproducing successfully, *P. flexilis* scarce or absent; undergrowth dominated by grasses, *Festuca thurberi* or *F. arizonica*. *Picea engelmannii* or *Pseudotsuga menziesii* sometimes also present ———————— 2
1. *Pinus flexilis* well represented, *P. aristata* scarce or absent; undergrowth dominated by shrubs, *Arctostaphylos uva-ursi* and/or *Juniperus communis* ———————— PIFL/ARUV HT
2. High-elevation mid and upper slopes and rocky ridges, generally over 10,500-feet (3,200-m) elevation, *Festuca thurberi* common ——— PIAR/FETH HT
2. Lower elevation, steep slopes and rocky ridges, generally under 9,800-feet (3,000-m) elevation, *Festuca thurberi* absent, *F. arizonica* common ———————— PIAR/FEAR HT

Picea engelmannii and *Abies lasiocarpa* Series

1. Undergrowth relatively well developed, although sometimes poorly represented; at least one understory species over 1% cover ———————— 2
1. Vascular plant undergrowth very sparse (seldom exceeding 10% total cover); often every species less than 1% cover ———————— ABLA/Moss HT
2. *Mertensia ciliata, Oxypolis fendleri, Cardamine cordifolia*, or other wet-site plants well represented; forests of high-elevation seeps and poorly drained benches ———————— ABLA/MECI HT
2. Wet-site plants poorly represented or absent — 3
3. *Vaccinium scoparium* or *V. myrtillus* well represented ———————— 4
3. *Vaccinium scoparium* or *V. myrtillus* poorly represented or absent ———————— 7
4. *Linnaea borealis* well represented ———————— ABLA/VAMY-LIBO HT
4. *Linnaea borealis* poorly represented or absent – 5
5. *Polemonium pulcherrimum* ssp. *delicatum* or *Ligularia amplectens* common ———————— PIEN/VAMY/POPU HT
5. *Polemonium pulcherrimum* ssp. *delicatum* or *Ligularia amplectens* scarce or absent ———————— 6
6. *Rubus parviflorus* well represented ———————— ABLA/VAMY-RUPA HT
6. *Rubus parviflorus* poorly represented or absent ———————— ABLA/VAMY HT
7. *Rubus parviflorus* well represented ———————— ABLA/RUPA HT
7. *Rubus parviflorus* poorly represented or absent ———————— 8
8. *Festuca thurberi* or *F. arizonica* scarce or absent; forests of the lower subalpine zone ABLA/EREX HT
8. *Festuca thurberi* or *F. arizonica* common; high-elevation open forests ———— PIAR/FETH HT

Picea pungens, Abies concolor, and *Pseudotsuga menziesii* Series

1. *Vaccinium* spp. well represented ———————— ABCO/VAMY HT
1. *Vaccinium* spp. poorly represented or absent — 2
2. *Picea pungens, Acer glabrum,* or *Erigeron eximius* common ———————— 3
2. *Picea pungens, Acer glabrum,* or *Erigeron eximius* scarce or absent ———————— 9
3. *Picea pungens* well represented, reproducing, and the indicated climax or co-climax ———— 4
3. *Picea pungens* absent or minor relative to *Abies concolor* and *Pseudotsuga menziesii* ———— 8
4. *Linnaea borealis* well represented ———————— PIPU/LIBO HT
4. *Linnaea borealis* poorly represented or absent – 5
5. *Carex foenea* abundant ——— PIPU/CAFO HT
5. *Carex foenea* less than 25% cover ———— 6
6. *Festuca arizonica* well represented ———————— PIPU/FEAR HT
6. *Festuca arizonica* poorly represented or absent ———————— 7
7. *Arctostaphylos uva-ursi* well represented ———————— PIPU/ARUV HT
7. *Arctostaphylos uva-ursi* poorly represented or absent ———————— PIPU/EREX HT
8. *Acer glabrum* dominant relative to *Erigeron eximius* or *Bromopsis ciliata*; undergrowths dominated by shrubs ———————— ABCO/ACGL HT
8. *Acer glabrum* minor or absent relative to *Erigeron eximius* or *Bromopsis ciliata*; undergrowths dominated by herbs ———— ABCO/EREX HT
9. *Abies concolor* common and reproducing successfully, not accidental ———————— 10
9. *Abies concolor* scarce or absent ———— 13
10. *Artcostaphylos uva-ursi* or *Quercus gambelii* well represented ———————— 11
10. *Arctostaphylos uva-ursi* or *Quercus gambelii* poorly represented or absent ———————— 12
11. *Arctostaphylos uva-ursi* well represented; *Quercus gambelii* poorly represented or absent ———————— ABCO/ARUV HT
11. *Arctostaphylos uva-ursi* poorly represented or absent; *Quercus gambelii* well represented ———————— ABCO/QUGA HT
12. *Festuca arizonica* common; other graminoids usually with greater than 1% cover – ABCO/FEAR HT
12. *Festuca arizonica* scarce or absent; all other herb species usually with less than 1% cover ———————— ABCO/Sparse HT
13. *Pinus flexilis* dominant or codominant with *Pseudotsuga menziesii*; *Arctostaphylos uva-ursi* and/or *Juniperus communis* well represented ———————— PIFL/ARUV HT
13. *Pinus flexilis* minor or absent, *Arctostaphylos uva-ursi* and *Juniperus communis* poorly represented or absent ———————— 14
14. *Quercus gambelii* well represented ———————— PSME/QUGA HT
14. *Quercus gambelii* poorly represented or absent ———————— 15
15. *Pinus aristata* present and reproducing successfully ———————— PIAR/FEAR HT
15. *Pinus aristata* scarce or absent PSME/FEAR HT

Pinus ponderosa Series

1. *Arctostaphylos uva-ursi* well represented ———————— PIPO/ARUV HT
1. *Arctostaphylos uva-ursi* poorly represented or absent ———————— 2
2. *Artemisia arbuscula* well represented ———————— PIPO/ARAR HT
2. *Artemisia arbuscula* poorly represented or absent ———————— 3
3. *Quercus gambelii* or *Q. undulata* well represented ———————— 4
3. *Quercus gambelii* or *Q. undulata* poorly represented or absent ———————— 5
4. *Quercus undulata* well represented ———————— PIPO/QUUN HT
4. *Quercus undulata* poorly represented or absent ———————— PIPO/QUGA HT
5. *Bouteloua gracilis* present and dominant or codominant in the undergrowth ———————— 6
5. *Bouteloua gracilis* absent or minor ———————— 7
6. *Festuca arizonica* present ———————— PIPO/FEAR HT, BOGR phase
6. *Festuca arizonica* absent ———————— PIPO/BOGR HT
7. *Festuca arizonica* and/or *Danthonia parryi* well represented ———————— PIPO/FEAR HT
7. *Festuca arizonica* and *Danthonia parryi* poorly represented or absent ———————— 8
8. *Muhlenbergia montana* common ———————— PIPO/MUMO HT
8. *Muhlenbergia montana* scarce or absent; woodlands on eolian sands ———————— PIPO/ORHY HT

APPENDIX 3

Successional Status of Major Tree Species Within Habitat Types (Excluding Scree and Riparian Habitat Types)

C = major climax S = major seral
c = minor climax s = minor seral

Habitat type	PIEN	ABLA	PIFL	PIPU	ABCO	PSME	PIPO	POTR	PIAR	QUGA	PIED	JUSC	JUMO
PIAR/FETH	C								C				
PIAR/FEAR						C		s	C				
PIEN/VAMY/POPU													
PIEN ph.	C	c							s				
ABLA ph.	C	C						s					
ABLA/MECI	C	C						s					
ABLA/Moss	C	C				s		s	s				
ABLA/VAMY	C	C	s		s	s		S	s				
ABLA/VAMY-LIBO	C	C		s	S	S		S					
ABLA/VAMY-RUPA	C	C			s	S		S					
ABLA/RUPA	C	C				S		S					
ABLA/EREX	C	C	s	s	S	S		S					
PIPU/LIBO	c	c	S	C	C	C		S					
PIPU/EREX	c		S	C	C	C		S					
PIPU/CAFO			s	C	c	C	S	S					
PIPU/ARUV			S	C	C	C	S	S					
PIPU/FEAR			s	C	c	C	S	S					
ABCO/VAMY	c	c	s	c	C	C	s	S					
ABCO/EREX	c		s	c	C	C	s	S					
ABCO/ACGL	c		s	c	C	C	s	S		s			
ABCO/Sparse			s	c	C	C	s	S	s				
ABCO/ARUV			s		C	C	S	s					
ABCO/FEAR			s		C	C	S	s					
ABCO/QUGA			s		C	C	S	s		S			
PIFL/ARUV	c		C			C		S					
PSME/FEAR			s			C	S	s			s		
PSME/QUGA													
FEAR ph.						C	S			S	s	s	
QUGA ph.						C	S			S	s	s	
PIPO/ARUV						c	C						
PIPO/FEAR													
DAPA ph.							C	s					
FEAR ph.							C				s		
BOGR ph.							C				c	c	c
PIPO/QUGA													
PIED ph.							C			S	C	c	c
FEAR ph.							C			S		c	
QUGA ph.							C			S	c	c	
PIPO/MUMO							C			s	c		c
PIPO/BOGR													
SCSC ph.							C				C	c	c
BOGR ph.							C				C	c	c
PIPO/QUUN							C			S	C	c	c
PIPO/ARAR							c			s	C	C	
PIPO/ORHY							C						c

APPENDIX 4

Average Tree Density or Average Shrub and Herbaceous Cover and Constancy for Habitat Types

In these tables, tree size classes are defined as follows:

Yng regen = trees less than 2 inches (5 cm) d.b.h.
Adv regen = trees 2–10 inches (5–25 cm) d.b.h.
Mature = trees larger than 10 inches (25 cm) d.b.h.

Occurrence of each species in each habitat type and phase is indicated by two values separated by a slash. The first indicates the mean density (in percent) per plot for the trees or mean cover (in percent) for the shrubs, graminoids, and forbs. In all cases, however, the first value is the mean for only the plots in which the species was present. The value to the right of the slash is the constancy for each species in the habitat type or phase; it is the percentage of the total number of plots in the group in which the species was found. A dot indicates that the species was not found in a group.

Table A1.— *Pinus aristata* series.

Species	PIAR/FETH HT (N = 7)	PIAR/FEAR HT (N = 4)
Trees		
Abies lasiocarpa		
Yng regen	<1/14	.
Adv regen	.	.
Mature	.	.
Picea engelmannii		
Yng regen	4/71	.
Adv regen	3/86	.
Mature	2/57	.
Pinus aristata		
Yng regen	3/71	3/100
Adv regen	7/71	6/100
Mature	5/86	7/100
Pinus flexilis		
Yng regen	<1/14	.
Adv regen	.	.
Mature	.	<1/25
Populus tremuloides		
Yng regen	.	2/25
Adv regen	.	.
Mature	.	.
Pseudotsuga menziesii		
Yng regen	.	2/50
Adv regen	.	2/50
Mature	.	2/75
Shrubs		
Juniperus communis	<1/14	<1/25
Ribes cereum	<1/14	2/50
Ribes montigenum	<1/43	.
Ribes wolfii	.	.
Symphoricarpos oreophilus	<1/29	1/25
Graminoids		
Carex rossii	<1/71	<1/50
Festuca arizonica	1/14	14/100
Festuca thurberi	22/100	.
Koeleria macrantha	<1/29	3/100
Muhlenbergia montana	<1/14	5/50
Poa fendleriana	<1/71	2/75
Forbs		
Achillea millefolium	<1/86	<1/25
Arnica cordifolia	2/29	.
Artemisia franserioides	<1/43	<1/75
Chamerion angustifolium	<1/71	.
Erigeron eximius	.	2/25
Fragaria americana	<1/14	<1/25
Fragaria ovalis	<1/29	.
Galium triflorum	.	.
Geranium caespitosum	<1/14	<1/25
Geranium richardsonii	<1/14	.
Oreochrysum parryi	<1/43	<1/25
Polemonium pulcherrimum	<1/57	.
Pseudocymopteris montanus	<1/29	.
Saxifraga bronchialis	<1/57	.
Senecio atratus	<1/29	.
Smilacina stellata	<1/29	<1/25
Thalictrum fendleri	<1/29	.
Trifolium dasyphyllum	<1/29	<1/50

Table A2.— *Picea engelmannii* and *Abies lasiocarpa* series.

Species	PIEN/VAMY/POPU HT		ABLA/MECI HT	ABLA/Moss HT	ABLA/VAMY HT	ABLA/VAMY-LIBO HT	ABLA/VAMY-RUPA	ABLA/RUPA HT	ABLA/EREX HT
	PIEN ph. (N = 15)	ABLA ph. (N = 38)	(N = 14)	(N = 14)	(N = 62)	(N = 21)	(N = 7)	(N = 11)	(N = 40)
Trees									
Abies concolor									
Yng regen	.	.	.	.	<1/6	4/29	<1/14	.	2/25
Adv regen	.	.	.	.	<1/6	<1/29	1/14	.	<1/22
Mature		.	.	.	<1/3	<1/5	<1/14	.	<1/15
Abies lasiocarpa									
Yng regen	2/67	63/100	37/100	38/93	64/97	68/100	59/100	65/100	38/97
Adv regen	2/47	14/100	13/100	9/93	15/89	17/86	9/100	16/100	10/97
Mature	<1/27	4/95	2/86	1/64	3/77	<1/29	2/71	3/82	2/57
Picea engelmannii									
Yng regen	43/93	31/95	19/100	29/100	34/98	43/90	29/100	11/73	21/92
Adv regen	24/100	14/95	9/93	26/100	14/95	13/90	8/100	7/73	9/90
Mature	14/100	11/100	10/100	8/100	7/94	5/76	6/100	6/100	6/85
Picea pungens									
Yng regen	.	.	.	.	<1/2	<1/14	.	.	<1/7
Adv regen		.	.	.	<1/2	<1/19	.	.	<1/5
Mature	.	.	.	.	<1/2	<1/10	.	.	<1/7
Pinus aristata									
Yng regen	.	.	.	<1/14	<1/2	.	.	.	.
Adv regen	<1/7	.	.	3/21	<1/2	.	.	.	.
Mature	<1/7	.	.	<1/14	<1/2	.	.	.	.
Pinus flexilis									
Yng regen	.	.	.	.	<1/5	<1/19	.	.	.
Adv regen	.	.	.	.	<1/6	.	.	<1/9	<1/5
Mature	.	<1/3	.	.	<1/3	.	.	.	<1/2
Populus tremuloides									
Yng regen	.	.	.	<1/7	<1/13	<1/14	2/14	<1/27	3/20
Adv regen	.	.	.	<1/14	3/18	3/33	.	<1/18	1/30
Mature	.	.	<1/7	<1/7	<1/3	<1/5	.	<1/27	<1/20
Pseudotsuga menziesii									
Yng regen	.	.	.	<1/14	<1/8	11/48	5/29	.	1/27
Adv regen	.	.	.	<1/7	<1/23	3/52	2/43	<1/27	1/35
Mature	.	.	.	<1/29	1/19	4/62	1/57	<1/36	2/42
Shrubs									
Acer glabrum	.	.	.	<1/7	<1/3	<1/29	2/43	2/27	<1/22
Juniperus communis	<1/13	<1/3	.	1/43	<1/31	<1/43	<1/14	.	<1/17
Linnaea borealis	.	.	.	.	<1/18	25/100	<1/14	.	<1/13
Lonicera involucrata	<1/13	<1/58	3/79	<1/14	<1/44	<1/71	3/100	2/82	1/52
Mahonia repens	.	.	.	<1/14	<1/15	<1/24	<1/14	<1/27	<1/27
Moneses uniflora	<1/27	<1/34	<1/79	<1/7	<1/32	<1/24	<1/14	<1/18	<1/27
Orthilia secunda	<1/40	<1/68	<1/79	<1/50	<1/73	<1/90	<1/86	1/82	<1/75
Pachistima myrsinites	<1/7	.	<1/7	<1/14	<1/47	6/57	4/71	2/73	2/50
Ribes montigenum	<1/80	<1/66	4/86	<1/7	<1/32	<1/24	<1/43	<1/36	1/57
Ribes wolfii	<1/20	<1/24	<1/43	.	<1/19	<1/14	1/43	<1/27	<1/27
Rubus parviflorus	.	.	.	.	<1/21	2/38	25/100	15/100	<1/35
Vaccinium myrtillus	31/100	37/100	2/57	2/57	50/100	25/95	31/100	<1/55	2/55
Graminoids									
Bromopsis ciliata	<1/53	<1/53	<1/79	<1/29	<1/55	<1/67	<1/100	<1/100	3/90
Calamagrostis canadensis	.	.	<1/14	.	<1/5	<1/5	.	.	<1/10
Carex bella	<1/20	<1/8	<1/29	.	.	.	.	.	<1/10
Carex rossii	<1/47	<1/11	<1/7	<1/64	<1/32	<1/24	<1/29	<1/9	<1/38
Festuca thurberi	<1/7	.	.	.	<1/5	.	<1/14	.	<1/7
Luzula parviflora	<1/60	<1/63	2/100	.	<1/18	.	<1/14	<1/18	<1/22
Trisetum spicatum (*T. montanum*)	<1/13	<1/18	<1/36	<1/29	<1/32	<1/71	<1/71	<1/55	<1/42

Table A2.—(continued)

Species	PIEN/VAMY/POPU HT		ABLA/MECI HT	ABLA/Moss HT	ABLA/VAMY HT	ABLA/VAMY-LIBO HT	ABLA/VAMY-RUPA	ABLA/RUPA HT	ABLA/EREX HT
	PIEN ph. (N = 15)	ABLA ph. (N = 38)	(N = 14)	(N = 14)	(N = 62)	(N = 21)	(N = 7)	(N = 11)	(N = 40)
Forbs									
Achillea millefolium	<1/47	<1/11	<1/21	<1/14	<1/18	<1/10	<1/14	<1/18	1/30
Actaea rubra ssp. *arguta*	.	<1/5	<1/14	<1/7	<1/8	<1/24	<1/57	<1/45	<1/25
Arnica cordifolia	1/47	3/79	4/57	<1/7	2/37	2/57	3/100	6/100	2/47
Artemisia franserioides	.	.	.	<1/21	<1/19	2/43	2/71	2/36	2/40
Bistorta vivipara	<1/27	<1/11	<1/36	.	.	.	.	.	.
Caltha leptosepala	<1/27	<1/13	3/29	.	<1/2	.	.	.	.
Cardamine cordifolia	.	.	10/93	.	.	.	.	.	.
Chamerion angustifolium	<1/47	<1/42	2/50	<1/14	<1/44	<1/48	<1/86	<1/55	<1/52
Erigeron coulteri	<1/20	<1/3	2/29	.	<1/2	.	.	<1/9	<1/10
Erigeron eximius	<1/27	2/55	<1/29	<1/43	2/60	5/62	10/100	6/91	16/97
Erigeron peregrinus	<1/20	<1/13	<1/29	<1/36	<1/19	<1/10	.	.	.
Fragaria americana	<1/7	<1/5	<1/7	.	<1/5	<1/14	<1/14	.	<1/17
Fragaria ovalis	<1/60	<1/47	<1/64	<1/79	<1/81	<1/76	<1/86	<1/55	3/77
Galium triflorum	.	.	<1/14	.	<1/2	<1/10	<1/43	<1/18	<1/17
Geranium richardsonii	<1/7	<1/47	3/79	<1/7	<1/45	<1/38	5/100	3/82	4/72
Lathyrus spp.	<1/7	<1/3	<1/21	<1/21	2/37	3/29	3/71	2/73	2/60
Ligularia amplectens	2/67	3/55	2/43	.	.	.	.	.	<1/5
Ligusticum porteri	<1/20	<1/53	2/71	<1/14	<1/29	<1/19	<1/29	2/45	<1/40
Mertensia ciliata	<1/53	<1/45	13/100	.	<1/15	<1/19	<1/43	<1/73	2/40
Mitella pentra	.	<1/13	1/50	.	<1/2	<1/5	.	<1/9	<1/20
Oreochrysum parryi	<1/47	<1/55	1/57	<1/29	2/61	3/81	7/100	9/91	6/75
Osmorhiza depauperata	<1/20	<1/66	2/86	<1/14	<1/47	<1/38	<1/100	<1/82	<1/75
Oxypolis fendleri	<1/20	<1/5	18/93	.	.	.	.	.	.
Pedicularis racemosa	<1/20	2/79	<1/57	<1/7	<1/55	<1/10	<1/29	<1/27	<1/17
Polemonium pulcherrimum	6/100	3/97	2/79	.	<1/6	<1/19	.	.	<1/10
Pseudocymopteris montanus	<1/60	<1/63	<1/50	<1/50	<1/47	<1/48	<1/14	<1/45	<1/57
Saxifraga bronchialis	<1/20	<1/5	.	<1/21	<1/6	<1/5	<1/14	.	<1/2
Saxifraga odontoloma	.	.	5/57	.	.	.	.	.	.
Senecio atratus	.	.	.	<1/7	.	.	.	.	.
Senecio triangularis	<1/7	.	6/79	.	.	.	.	.	<1/2
Smilacina racemosa	.	<1/5	<1/29	.	<1/19	<1/38	<1/100	1/91	<1/42
Smilacina stellata	.	.	2/14	.	<1/11	.	<1/57	<1/45	<1/45
Streptopus amplexifolius	.	<1/16	1/71	.	<1/6	<1/14	<1/14	<1/45	<1/27
Thalictrum fendleri	<1/7	<1/8	1/57	.	<1/21	<1/14	2/86	3/82	2/50
Trautvetteria carolinensis	.	2/5	2/7	.	<1/6	.	.	3/9	1/5
Trifolium dasyphyllum	2/13	<1/3	.	.	.	.	.	.	<1/2
Viola canadensis	<1/7	<1/24	<1/50	<1/7	<1/29	<1/48	<1/86	1/100	2/72

Table A3.—Mixed-conifer series.

Species	PIPU/LIBO HT (N = 8)	PIPU/EREX HT (N = 13)	PIPU/CAFO HT (N = 5)	PIPU/ARUV HT (N = 4)	PIPU/FEAR HT (N = 9)	ABCO/VAMY HT (N = 13)	ABCO/EREX HT (N = 18)
Trees							
Abies concolor							
Yng regen	10/63	7/62	2/60	5/75	2/22	52/100	17/89
Adv regen	4/63	3/62	2/40	2/50	3/11	9/100	6/89
Mature	<1/13	1/46	<1/40	.	<1/22	3/77	4/67
Abies lasiocarpa							
Yng regen	8/50	<1/15	.	<1/25	.	<1/8	.
Adv regen	1/38	<1/15	.	.	.	<1/38	<1/11
Mature	<1/13	.	.	.	.	.	.
Juniperus scopulorum							
Yng regen	.	<1/8	.	.	.	.	.
Adv regen	.		.	.	.	.	.
Mature	.	.	.	.	.	.	.
Picea engelmannii							
Yng regen	4/50	<1/15	.	.	.	<1/23	<1/11
Adv regen	2/50	<1/23	.	.	.	<1/23	<1/17
Mature	<1/25	.	.	.	.	<1/8	.
Picea pungens							
Yng regen	22/100	9/92	21/100	14/100	11/100	2/15	<1/33
Adv regen	12/100	8/100	8/100	7/100	12/100	<1/15	<1/39
Mature	4/88	3/77	7/100	3/50	3/89	<1/8	<1/22
Pinus flexilis							
Yng regen	2/63	4/62	.	2/50	<1/44	<1/15	<1/17
Adv regen	<1/13	<1/31	<1/40	<1/50	<1/11	<1/8	<1/28
Mature	<1/13	<1/8	.	.	<1/11	.	<1/6
Pinus ponderosa							
Yng regen	<1/13	.	.	11/50	1/33	<1/8	.
Adv regen	.	<1/8	4/40	2/50	5/56	<1/23	<1/17
Mature	<1/13	<1/8	2/80	2/50	1/56	1/38	<1/6
Populus tremuloides							
Yng regen	2/63	2/62	1/40	44/100	3/56	6/54	4/39
Adv regen	<1/25	2/46	<1/20	2/75	2/67	6/77	3/67
Mature	<1/13	<1/15	.	.	<1/11	<1/31	<1/22
Pseudotsuga menziesii							
Yng regen	30/100	13/85	16/80	21/100	3/89	11/92	11/89
Adv regen	7/100	7/85	3/100	14/100	1/78	6/92	8/94
Mature	5/75	5/85	1/40	3/75	<1/33	5/85	6/94
Shrubs							
Acer glabrum	<1/50	<1/31	.	.	.	7/62	1/44
Amelanchier alnifolia	<1/38	<1/15	2/20	<1/50	<1/11	2/62	<1/17
Arctostaphylos uva-ursi	<1/50	<1/23	<1/20	24/100	<1/44	6/31	<1/11
Cercocarpus montanus	.	.	.	.	.	.	.
Clematis columbiana	<1/88	<1/46	.	<1/25	<1/11	<1/38	<1/56
Holodiscus dumosus	.	<1/8	.	.	.	.	.
Jamesia americana	.	<1/15	.	.	.	<1/15	1/28
Juniperus communis	2/88	2/62	2/100	6/75	<1/78	1/62	<1/28
Linnaea borealis	24/100	<1/8	.	.	.	<1/23	.
Mahonia repens	<1/25	4/31	1/20	1/50	<1/11	4/92	<1/61
Orthilia secunda	<1/100	<1/54	<1/20	<1/25	.	<1/54	<1/39
Pachistima myrsinites	9/100	2/77	<1/20	<1/50	<1/11	6/100	1/61
Physocarpus monogynus	.	2/8	.	.	.	.	<1/11
Prunus virginiana	.	<1/8	<1/20	<1/25	<1/11	<1/15	<1/17
Quercus gambelii	<1/25	<1/15	<1/40	<1/50	<1/44	<1/8	<1/28
Ribes cereum	<1/13	<1/15	.	.	.	.	.
Ribes inerme	<1/13	<1/23	<1/40	.	<1/11	.	<1/11
Rosa spp.	2/88	1/62	1/20	2/100	<1/44	<1/77	1/72
Rubus parviflorus	5/63	<1/31	.	.	.	5/62	<1/78
Swida sericea	<1/25	<1/23	.	<1/25	.	<1/8	<1/6
Symphoricarpos oreophilus	<1/75	2/54	<1/20	<1/25	<1/22	1/62	2/56
Vaccinium myrtillus	3/63	<1/15	.	.	.	22/100	.

Table A3.—(continued)

Species	ABCO/ACGL HT (N = 22)	ABCO/Sparse HT (N = 26)	ABCO/ARUV HT (N = 7)	ABCO/FEAR HT (N = 10)	ABCO/QUGA HT (N = 13)	PIFL/ARUV HT (N = 4)	PSME/FEAR HT (N = 7)	PSME/QUGA HT	
								FEAR ph. (N = 12)	QUGA ph. (N = 11)
Trees									
Abies concolor									
Yng regen	27/100	15/85	22/86	10/90	22/92	.		<1/25	<1/9
Adv regen	11/95	5/85	5/100	4/90	10/100	<1/25	<1/14	<1/8	.
Mature	3/68	2/54	1/57	1/60	2/46	.	.	.	.
Abies lasiocarpa									
Yng regen	<1/14	.	.	.	.	<1/25	.	.	.
Adv regen	.	.	.	.	.	.	.	.	.
Mature	.	.	.	.	.	.	.	.	.
Juniperus scopulorum									
Yng regen	.	<1/8	.	<1/10	<1/8	.	.	2/42	3/45
Adv regen	.	<1/8	.	.	.	.	.	<1/17	1/55
Mature	.	.	.	.	.	.	.	.	<1/18
Picea engelmannii									
Yng regen	<1/18	<1/8	.	.	.	2/25	.	.	.
Adv regen	<1/18	<1/12	.	.	.	6/75	.	.	.
Mature	.	.	.	.	.	<1/25	.	.	.
Picea pungens									
Yng regen	<1/5	<1/15	.	.	<1/23	.	<1/29	<1/8	.
Adv regen	<1/9	<1/12	.	.	<1/15	.	.	.	<1/9
Mature	.	<1/4	.	.	.	.	<1/14	.	.
Pinus flexilis									
Yng regen	2/41	2/46	2/43	4/40	<1/38	8/100	1/57	<1/17	<1/9
Adv regen	<1/9	1/38	1/43	2/40	<1/31	13/100	<1/14	.	<1/18
Mature	<1/14	<1/19	.	<1/20	<1/31	9/100	.	.	.
Pinus ponderosa									
Yng regen	<1/9	<1/15	4/57	3/40	<1/38	.	<1/29	3/50	1/64
Adv regen	.	2/38	7/86	3/50	2/69	<1/25	<1/43	3/83	5/82
Mature	<1/14	1/38	4/86	2/50	2/69	.	2/71	3/58	2/91
Populus tremuloides									
Yng regen	2/41	2/38	.	3/30	1/23	<1/25	7/43		.
Adv regen	1/27	<1/27	1/29	<1/20	1/15	<1/50	.	.	.
Mature	<1/5	.	.	.	<1/8	.	.	.	.
Pseudotsuga menziesii									
Yng regen	13/86	13/92	11/100	14/100	7/77	3/75	7/100	14/92	14/100
Adv regen	7/91	12/96	6/71	5/80	4/77	2/75	4/100	7/100	5/100
Mature	3/77	6/88	4/71	2/80	2/62	3/100	2/100	2/83	3/100
Shrubs									
Acer glabrum	14/100	<1/27	<1/14	.	<1/15	.	.	<1/8	.
Amelanchier alnifolia	5/77	<1/19	<1/14	<1/10	<1/15	.	<1/29	<1/25	4/91
Arctostaphylos uva-ursi	<1/9	<1/31	24/100	1/30	<1/8	25/100	3/71	<1/17	.
Cercocarpus montanus	.	<1/8	<1/14	.	<1/15	.	<1/29	2/58	<1/36
Clematis columbiana	2/73	<1/54	<1/29	<1/60	<1/15	.	<1/14	<1/50	<1/9
Holodiscus dumosus	<1/14	<1/19	.	<1/20	<1/8	<1/25	<1/14	<1/8	.
Jamesia americana	1/18	<1/15	<1/14	.	3/23	<1/75	.	.	.
Juniperus communis	<1/27	2/54	1/57	<1/40	<1/31	4/100	1/71	<1/17	.
Linnaea borealis	<1/9	.	.	.	.	.	.	.	.
Mahonia repens	4/77	2/58	<1/43	<1/20	1/92	.	1/43	<1/25	1/91
Orthilia secunda	<1/55	<1/23	.	.		.		.	.
Pachistima myrsinites	4/91	<1/54	3/71	<1/10	<1/46	<1/25	<1/14	<1/25	1/73
Physocarpus monogynus	4/18	2/12	.	<1/10	<1/8	.		<1/42	.
Prunus virginiana	<1/36	<1/19	.	.	<1/38	.	<1/29	<1/33	<1/9
Quercus gambelii	2/55	<1/31	<1/43	1/20	22/100		.	23/100	35/100
Ribes cereum	.	<1/12	<1/14	<1/40	<1/8	.	<1/14	<1/25	<1/9
Ribes inerme	<1/5	<1/4	.	<1/10	<1/8	.	<1/14	.	.
Rosa spp.	<1/82	<1/81	<1/57	<1/50	1/69	<1/75	<1/71	<1/42	3/73
Rubus parviflorus	1/45	<1/4	.	.	.	.	.	.	.
Swida sericea	2/18	.	.	.	.	.	.	<1/8	.
Symphoricarpos oreophilus	8/82	3/77	<1/57	<1/30	5/54	<1/25	<1/43	3/67	4/73
Vaccinium myrtillus	<1/14	<1/15	.	.	.	.	.	.	.

Table A3.—(continued)

Species	PIPU/LIBO HT (N = 8)	PIPU/EREX HT (N = 13)	PIPU/CAFO HT (N = 5)	PIPU/ARUV HT (N = 4)	PIPU/FEAR HT (N = 9)	ABCO/VAMY HT (N = 13)	ABCO/EREX HT (N = 18)
Graminoids							
Bromopsis ciliata	<1/88	<1/77	<1/80	<1/100	<1/67	<1/92	3/100
Carex foenea	14/100	3/54	48/100	.	2/44	.	<9/50
Carex geyeri	.	.	7/20	.	<1/11	.	.
Carex rossii	<1/25	<1/54	<1/20	<1/75	<1/44	<1/62	<1/61
Danthonia parryi	.	.	1/40	<1/50	5/67	.	<1/6
Elymus glaucus	<1/25	.	<1/40	.	.	.	<1/6
Festuca arizonica	<1/13	<1/31	<1/20	2/50	11/100	.	<1/6
Festuca thurberi	.	<1/15	<1/60	.	<1/22	.	<1/17
Koeleria macrantha	<1/13	<1/38	<1/20	<1/100	2/100	<1/15	<1/33
Muhlenbergia montana	.	<1/23	.	<1/75	3/67	.	.
Oryzopsis asperifolia	2/50	<1/23	<1/40	<1/50	.	<1/54	<1/17
Poa fendleriana	<1/13	<1/46	<1/60	<1/50	2/100	<1/23	<1/22
Sitanion hystrix	<1/8	<1/40	<1/25	<1/78	.	<1/8	<1/17
Trisetum spicatum	<1/88	<1/23	1/60	.	.	<1/15	<1/67
Forbs							
Achillea millefolium	<1/38	<1/23	1/100	<1/75	<1/89	1/23	<1/61
Antennaria rosea	<1/25	<1/38	1/80	<1/75	<1/100	<1/15	<1/22
Arnica cordifolia	1/25	.	<1/20	.	<1/11	1/38	<1/6
Artemisia franserioides	1/63	1/46	.	<1/25	<1/22	1/69	4/67
Artemisia ludoviciana	.	<1/8	<1/40	<1/50	<1/56	.	.
Erigeron eximius	3/100	4/77	<1/20	<1/25	.	2/69	22/83
Erigeron formosissimus	.	.	1/60	<1/50	2/56	.	.
Erigeron subtrinervis	.	<1/8	.	<1/50	<1/56	.	<1/11
Fragaria americana	2/63	2/54	4/80	2/50	<1/56	<1/15	<1/39
Fragaria ovalis	3/88	<1/69	11/100	6/100	1/89	1/62	2/89
Galium triflorum	<1/38	.	2/60	.	<1/11	<1/8	1/28
Geranium caespitosum	.	<1/8	.	<1/25	<1/44	<1/15	<1/6
Geranium richardsonii	2/38	<1/38	4/100	<1/50	.	<1/46	2/67
Lathyrus spp.	2/63	<1/54	4/100	<1/75	2/56	4/69	12/89
Ligusticum porteri	<1/13	<1/8	.	.	<1/11	<1/15	.
Oreochrysum parryi	<1/63	2/77	<1/60	.	<1/44	<1/69	4/78
Osmorhiza depauperata	<1/38	<1/31	<1/80	.	<1/11	<1/54	<1/50
Pedicularis racemosa	.	.	<1/20	.	.	.	.
Potentilla hippiana	.	<1/15	<1/80	<1/75	1/100	.	.
Pseudocymopteris montanus	<1/50	<1/23	<1/100	<1/75	<1/67	<1/54	<1/61
Smilacina racemosa	<1/88	<1/38	<1/20	<1/25	<1/11	<1/62	<1/22
Smilacina stellata	<1/25	1/54	<1/40	<1/100	<1/33	<1/38	1/39
Thalictrum fendleri	3/88	3/46	1/40	.	<1/67	<1/15	2/56
Thermopsis spp.	<1/13	.	<1/20	.	<1/33	1/38	4/17
Vicia americana	<1/13	<1/46	<1/60	<1/75	<1/67	<1/23	<1/44
Viola canadensis	<1/63	<1/23	1/100	<1/50	.	<1/46	<1/61

Table A3.—(continued)

Species	ABCO/ACGL HT (N = 22)	ABCO/Sparse HT (N = 26)	ABCO/ARUV HT (N = 7)	ABCO/FEAR HT (N = 10)	ABCO/QUGA HT (N = 13)	PIFL/ARUV HT (N = 4)	PSME/FEAR HT (N = 7)	PSME/QUGA HT	
								FEAR ph. (N = 12)	QUGA ph. (N = 11)
Graminoids									
Bromopsis ciliata	<1/95	<1/50	<1/57	<1/40	<1/77	<1/25	<1/43	<1/50	<1/45
Carex foenea	<1/14	<1/15	<1/14	<1/10	<1/23	.	.	<1/8	<1/18
Carex geyeri	2/23	.	.	.	<1/8	.	<1/14	<1/8	2/45
Carex rossii	<1/64	<1/81	<1/57	<1/90	2/85	<1/75	<1/86	<1/17	<1/36
Danthonia parryi	.	.	<1/14	1/20	.	<1/25	<1/43	4/25	.
Elymus glaucus	<1/14	<1/4	.	.	.	.	.	.	.
Festuca arizonica	<1/5	<1/19	<1/43	8/100	.	<1/25	11/100	5/100	.
Festuca thurberi	.	.	.	<1/20	.	.	.	.	.
Koeleria macrantha	<1/23	<1/65	<1/100	<1/70	<1/54	<1/75	<1/100	<1/100	<1/36
Muhlenbergia montana	.	<1/19	<1/71	2/60	<1/23	.	2/57	3/75	.
Oryzopsis asperifolia	<1/18	<1/8	.	.	<1/8	.	.	.	.
Poa fendleriana	<1/50	<1/69	<1/71	1/90	<1/77	<1/25	4/100	1/92	2/100
Sitanion hystrix	<1/9	<1/19	<1/43	<1/40	<1/31	.	<1/86	<1/83	<1/55
Trisetum spicatum	<1/41	<1/15	.	.	.	.	.	.	.
Forbs									
Achillea millefolium	<1/14	<1/23	<1/29	<1/40	2/46	.	<1/14	<1/42	<1/18
Antennaria rosea	<1/5	<1/35	<1/43	<1/30	.	<1/50	<1/86	<1/42	<1/36
Arnica cordifolia	2/27	<1/15	.	.	<1/8	.	.	.	.
Artemisia franserioides	1/55	<1/50	.	<1/20	<1/8	<1/25	<1/14	<1/8	.
Artemisia ludoviciana	.	<1/15	<1/14	<1/30	<1/31	.	<1/43	<1/67	<1/36
Erigeron eximius	2/59	<1/23	.	<1/30	<1/8	.	.	.	.
Erigeron formosissimus	.	<1/4	<1/14	<1/50	.	.	.	<1/8	<1/9
Erigeron subtrinervis	.	<1/12	<1/29	.	<1/23	.	<1/43	<1/50	<1/18
Fragaria americana	<1/50	<1/46	<1/14	<1/40	<1/23	.	<1/14	<1/42	<1/9
Fragaria ovalis	<1/50	<1/35	<1/71	<1/50	1/54	<1/25	<1/29	<1/8	<1/9
Galium triflorum	<1/14	.	.	.	.	.	<1/14	.	.
Geranium caespitosum	<1/5	<1/4	.	<1/10	<1/31	<1/50	<1/71	<1/17	<1/18
Geranium richardsonii	<1/32	<1/4	.	.	<1/8	.	.	.	.
Lathyrus spp.	3/68	<1/23	<1/14	3/50	<1/46	.	<1/29	1/42	<1/9
Ligusticum porteri	1/23	.	.	.	.	.	.	.	.
Oreochrysum parryi	<1/50	<1/42	<1/43	<1/10	<1/46	<1/50	<1/14	<1/17	.
Osmorhiza depauperata	<1/36	.	.	.	<1/15	.	.	.	.
Pedicularis racemosa	.	.	.	.	.	.	.	.	.
Potentilla hippiana	.	<1/8	.	<1/30	.	.	<1/57	<1/50	<1/9
Pseudocymopteris montanus	<1/23	<1/19	<1/29	<1/20	<1/38	.	<1/14	<1/50	.
Smilacina racemosa	<1/59	<1/19	.	.	<1/15	.	.	<1/8	<1/36
Smilacina stellata	<1/23	<1/19	<1/14	<1/20	<1/8	.	<1/43	<1/8	<1/27
Thalictrum fendleri	<1/59	<1/19	.	<1/20	<1/62	.	<1/14	1/50	<1/18
Thermopsis spp.	<1/9	.	<1/43	<1/20	.	.	<1/14	3/8	.
Vicia americana	<1/18	<1/15	<1/14	<1/30	<1/31	.	<1/29	<1/42	<1/45
Viola canadensis	<1/55	<1/4	.	.	<1/8	.	.	.	.

Table A4.— *Pinus ponderosa* series

Species	PIPO/ARUV HT	PIPO/FEAR HT			PIPO/QUGA HT			PIPO/MUMO HT	PIPO/BOGR HT		PIPO/QUUN HT	PIPO/ARAR HT	PIPO/ORHY HT
	(N = 10)	DAPA ph (N = 7)	FEAR ph (N = 18)	BOGR ph (N = 8)	FEAR ph. (N = 21)	QUGA ph. (N = 26)	PIED ph (N = 14)	(N = 9)	SCSC ph. (N = 14)	BOGR ph. (N = 18)	(N = 9)	(N = 6)	(N = 1)
Trees													
Juniperus monosperma													
Yng regen	1/10			<1/25			<1/43	1/78	4/50	2/61	1/22		2/100
Adv regen				1/25		1/4	1/7		<1/21	1/33			1/100
Mature													
Juniperus scopulorum													
Yng regen		1/14	1/11	2/63	1/24	1/35	1/21	<1/22	1/36	4/44	1/44	17/100	
Adv regen		<1/14	<1/6	1/25	<1/10	<1/23	1/14		<1/21	2/22	1/33	7/83	
Mature				1/13	1/5	1/4			<1/7	<1/17	1/22	<1/33	
Pinus edulis													
Yng regen	1/10	<1/29	2/56	6/75	1/38	1/38	10/93	2/44	3/50	8/94	7/67	18/100	
Adv regen			<1/11	4/75			4/100		<1/29	4/67	2/44	7/100	
Mature				1/13			1/14			1/11	1/11	<1/33	
Pinus ponderosa													
Yng regen	45/100	11/100	9/94	6/63	5/90	7/96	4/79	9/78	8/93	3/94	4/78	<1/50	1/100
Adv regen	18/100	4/71	5/94	6/88	11/95	7/88	4/93	12/100	6/93	4/89	1/56	<1/33	1/100
Mature	6/100	5/100	5/100	3/100	4/100	5/100	3/100	5/100	3/100	3/100	2/89	1/67	1/100
Pseudotsuga menziesii													
Yng regen	2/40	1/43	<1/22		<1/33	1/27	1/14	1/11	1/21	1/11			
Adv regen	<1/30	<1/14	<1/17	<1/13	1/14	<1/23	<1/14			<1/6			
Mature													
Shrubs													
Arctostaphylos uva-ursi	44/100	1/29	1/22		1/10	<1/8	1/7	<1/11					
Artemisia arbuscula												18/100	
Ceanothus fendleri	1/30		<1/6	<1/13	<1/24	<1/38		<1/33					
Cercocarpus montanus	<1/40	<1/14	<1/56	3/63	1/24	3/69	2/86	<1/33	1/21	<1/17	1/56		<1/100
Mahonia repens	<1/10		<1/6		<1/38	<1/42	<1/21	<1/11	<1/14				
Purshia tridentata					1/10	1/23	<1/7						
Quercus gambelii	<1/50	<1/29	<1/22	1/50	28/100	27/100	26/100	1/44	1/21	1/67	3/44	4/33	
Quercus undulata	<1/10		<1/6			1/8	<1/14	<1/11	1/21	<1/11	33/100		
Rhus aromatica			<1/6	<1/25	<1/5	<1/8	<1/21		<1/36	<1/39	<1/33		
Ribes cereum	<1/10	1/57	<1/50	<1/38	<1/14	<1/4	<1/21		<1/21	<1/17		<1/67	
Symphoricarpos oreophilus	1/20	<1/29	<1/44	1/25	3/57	1/35	1/21	<1/11		<1/11		<1/83	
Yucca glauca			<1/17	<1/38	<1/5	<1/19	<1/36	1/11		<1/6	1/11	1/67	
Graminoids													
Andropogon gerardi	1/10		1/11	1/50	1/10	1/15	<1/21		1/36	1/11	<1/67		
Blepharoneuron tricholepis		<1/29	<1/33	<1/63	1/19	1/19	<1/43	<1/22	4/64	2/39	1/56		
Bouteloua curtipendula			<1/6	<1/38	<1/5	<1/23	1/14		<1/29	<1/17	<1/67		
Bouteloua gracilis			<1/17	3/100	<1/5	<1/19	<1/57	<1/22	6/64	9/100	2/89	2/83	
Carex spp	<1/50	<1/29	<1/22	2/63	<1/14	<1/31	2/57	2/67	2/43	1/28	2/44		
Carex heliophila	<1/20				<1/14	1/12	1/14	1/11	1/21	1/17	1/22	4/100	
Carex rossii	<1/30	3/43	<1/67	<1/25	1/48	2/65	1/29	<1/22	<1/14	1/44	<1/22		
Danthonia parryi		17/100			<1/19	<1/8							
Festuca arizonica	2/60	13/100	11/100	13/100	6/100		2/57			<1/6	1/33	<1/50	
Koeleria macrantha	<1/90	1/100	1/89	<1/63	1/81	<1/69	<1/93	3/100	<1/64	<1/83	<1/78	1/100	
Muhlenbergia montana	2/100	4/86	4/100	10/100	2/62	2/73	3/86	9/100	5/86	2/83	5/100		
Oryzopsis hymenoides		1/14	<1/11	<1/13	<1/14	<1/4	<1/7			<1/6			<1/100
Poa fendleriana	1/70	3/100	2/94	<1/63	2/95	3/96	2/100	2/89	2/100	4/89	1/78	<1/83	
Schizachyrium scoparium	<1/20		<1/22	4/75	2/19	2/27	1/29	<1/44	15/100	1/50	6/100		6/100
Sitanion hystrix	<1/80	2/100	<1/83	<1/100	<1/86	<1/88	<1/93	2/100	1/86	<1/100	<1/89	<1/100	<1/100
Forbs													
Achillea millefolium	1/30	2/57	<1/33		<1/57	1/35	1/7	1/11	<1/7	1/11			
Antennaria rosea	<1/50	2/100	<1/67	<1/38	<1/76	<1/31	<1/29	<1/67	<1/43	<1/33			
Artemisia carruthii	<1/20	<1/57	<1/44	<1/25	<1/14	<1/8	<1/21	<1/44	<1/29	<1/56			
Artemisia ludoviciana	<1/30	<1/29	<1/50	1/75	1/71	<1/73	<1/71	<1/33	<1/43	<1/39	1/89	<1/33	
Erigeron flagellaris	<1/10	<1/57	<1/28	<1/75	<1/52	<1/31	<1/50	<1/56	1/50	<1/50	<1/67	1/83	
Erigeron formosissimus	<1/40	1/57	<1/28		<1/33	<1/15	<1/21	<1/56	<1/29	<1/11			
Erigeron subtrinervis		<1/57	<1/33		<1/43	<1/12	<1/21	<1/11	<1/14	<1/6			
Heterotheca fulcrata	<1/40	<1/29	<1/56	<1/75	<1/43	<1/50	<1/64	<1/56	2/86	<1/89	<1/78		<1/100
Hymenoxys acaulis		1/14	<1/17	<1/25	<1/10	<1/15	<1/29	<1/44	<1/21	<1/33	1/22		
Hymenoxys richardsonii		<1/29	<1/33	<1/38	1/14	1/12	<1/50	<1/67	<1/7	<1/39	<1/11		
Lotus wrightii				<1/25	<1/14	1/23	<1/14	<1/33	2/43	1/39			
Potentilla hippiana	<1/30	3/100	<1/78	1/50	<1/52	<1/12	<1/14	<1/22	<1/7				
Solidago spp	<1/40		<1/11	<1/25	<1/19	<1/27	<1/21	<1/11	2/29	<1/6	<1/44		
Vicia americana	<1/20	1/43	<1/6		<1/52	<1/27	<1/14		<1/14	<1/11			

Table A5.—Scree forest habitat types.

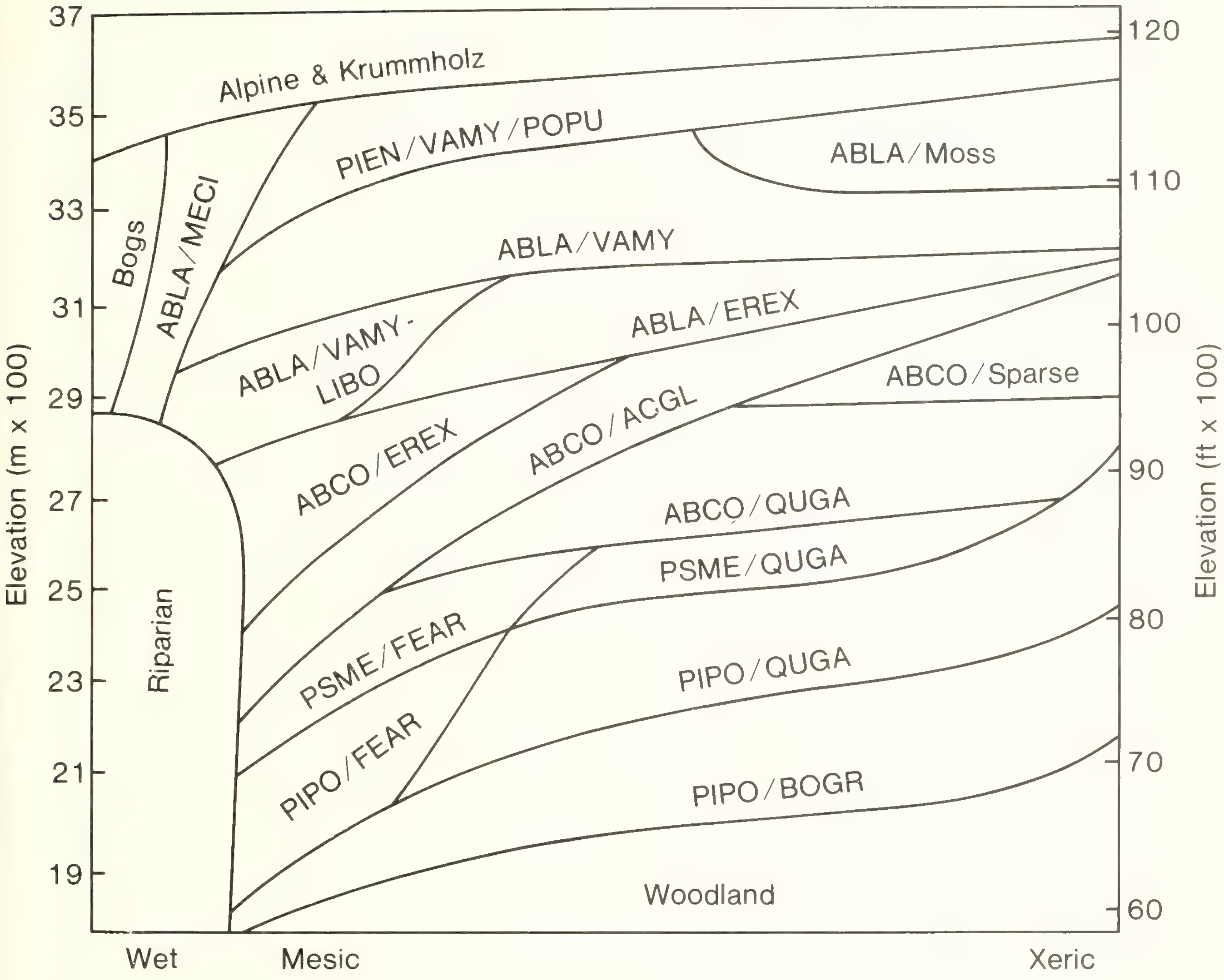
Species	PIAR/RIMO HT (N = 1)	PIEN/SABR HT (N = 8)	ABLA/SABR HT (N = 1)	ABCO/HODU HT (N = 4)	PSME/HODU HT (N = 4)	PIPO/RIIN HT (N = 1)
Trees						
Abies concolor						
Yng regen				2/75	<1/25	
Adv regen				2/50		
Mature				2/75		
Abies lasiocarpa						
Yng regen		<1/13	16/100		<1/25	
Adv regen	.	<1/38	20/100			
Mature	.	<1/25	3/100			
Juniperus scopulorum						
Yng regen		.	.	<1/25	<1/50	1/100
Adv regen	.	.		2/25		
Mature						
Picea engelmannii						
Yng regen		3/100	1/100			
Adv regen		4/100	.			
Mature	1/100	4/88				
Pinus aristata						
Yng regen	3/100			<1/25	<1/50	
Adv regen	.			<1/25		
Mature	9/100			.		
Pinus edulis						
Yng regen				1/25		2/100
Adv regen						1/100
Mature						
Pinus flexilis						
Yng regen		<1/13		5/50	2/50	
Adv regen				2/25	2/50	
Mature		.		1/50	1/50	.
Pinus ponderosa						
Yng regen				<1/25	.	2/100
Adv regen				<1/50	1/50	
Mature		.		1/50	2/50	1/100
Populus tremuloides						
Yng regen		9/38				
Adv regen		3/38				
Mature						
Pseudotsuga menziesii						
Yng regen				2/75	4/100	
Adv regen				<1/25	2/100	1/100
Mature		<1/13		<1/50	5/100	.
Shrubs						
Acer glabrum					<1/25	
Cercocarpus montanus				<1/25	5/50	
Holodiscus dumosus		.		4/75	3/75	
Jamesia americana	.	<1/13	.	2/50	<1/25	
Juniperus communis	<1/100	4/75	2/100		<1/50	
Pentaphylloides floribunda	<1/100	<1/25				
Quercus gambelii		.				3/100
Ribes cereum	.			1/50	<1/75	
Ribes inerme	.		.	3/75	<1/25	1/100
Ribes montigenum	9/100	<1/50	<1/100	.	<1/25	
Ribes wolfii	.	<1/38		.	<1/25	
Rosa spp.		<1/13		<1/25	<1/25	
Salix scouleriana				<1/25	.	
Symphoricarpos oreophilus	.			<1/50	<1/50	
Graminoids						
Carex geyeri		<1/25	.			
Carex rossii		<1/100	<1/100	<1/75	<1/100	
Festuca arizonica		.	.	<1/50	<1/75	
Festuca brachyphylla	.	<1/75	<1/100		<1/25	
Festuca thurberi	<1/100	<1/38			<1/25	
Koeleria macrantha	.	<1/50	<1/100	<1/50	<1/25	
Muhlenbergia montana		.			<1/75	<1/100
Poa fendleriana	<1/100	<1/38		3/50	<1/100	<1/100
Forbs						
Antennaria rosea	.	<1/25		<1/50		
Artemisia franserioides	.	.		<1/50		
Fragaria americana		<1/25		<1/50	<1/25	
Fragaria ovalis		<1/25	<1/100			.
Helianthella parryi	.	.	.		<1/25	<1/100
Oreochrysum parryi	.	<1/13	.	.	<1/25	
Saxifraga bronchialis	3/100	<1/63	<1/100	<1/25	<1/25	
Sedum lanceolatum	<1/100	<1/25	.	.		
Senecio atratus	<1/100	<1/50	<1/100	.		
Senecio fendleri	<1/100	<1/13	.	1/25	<1/100	<1/100
Valeriana capitata	.	.	<1/100	<1/25	<1/25	

Table A6.—Riparian forest habitat types

Species	PIEN/HESP HT (N = 3)	PIPU/SWSE HT (N = 7)	PIPU/POPR HT (N = 6)	ABCO/GATR HT (N = 4)	PIPO/POPR HT (N = 3)
Trees					
Abies concolor					
Yng regen	6/33	35/43	5/83	36/100	
Adv regen	13/33	5/57	4/67	14/100	
Mature	<1/33	<1/29	1/33	3/75	
Abies lasiocarpa					
Yng regen	5/67		<1/17		
Adv regen	1/33		<1/17		
Mature	1/33				
Acer negundo					
Yng regen					7/67
Adv regen					9/67
Mature					2/67
Juniperus scopulorum					
Yng regen		1/43	<1/17	3/75	6/67
Adv regen		1/14		2/75	3/33
Mature					
Picea engelmannii					
Yng regen	4/100		<1/17		
Adv regen	8/100	<1/14	<1/17		
Mature	5/100				
Picea pungens					
Yng regen	1/33	7/100	11/100		
Adv regen	2/33	11/100	7/100		
Mature	<1/33	5/100	4/67		
Pinus ponderosa					
Yng regen					4/67
Adv regen		<1/14		<1/50	14/100
Mature		<1/14		1/50	3/100
Populus angustifolia					
Yng regen	8/67	11/29		4/75	
Adv regen	3/100	<1/14	<1/16	1/25	<1/33
Mature	2/100	1/43		2/50	<1/33
Pseudotsuga menziesii					
Yng regen	3/33	4/71	2/83	12/75	<1/67
Adv regen	<1/33	3/71	1/50	2/100	
Mature	<1/33	<1/43			
Shrubs					
Acer glabrum	5/33	11/43	<1/17	18/100	
Acer negundo		<1/29		<1/25	40/67
Alnus tenuifolia	24/67	14/86	2/33	11/100	
Clematis columbiana			<1/33	<1/50	
Clematis ligusticifolia		1/14		6/50	12/33
Jamesia americana			8/17	<1/50	
Lonicera involucrata	9/100	2/43	1/17		
Mahonia repens	<1/33	<1/43		<1/50	
Pachistima myrsinites	2/33	<1/57	1/50	8/50	
Prunus virginiana		<1/43	3/33	3/100	<1/33
Quercus gambelii	<1/33	<1/43	<1/33	35/100	24/100
Ribes inerme		3/43	1/50	3/75	<1/33
Ribes montigenum	4/67	<1/29			
Rosa spp	<1/100	2/86	6/67	<1/75	
Rubus parviflorus	<1/33	1/29	1/17		
Salix spp	<1/33	12/57	3/17	4/25	
Swida sericea	6/67	6/100		<1/50	
Symphoricarpos oreophilus	<1/67	1/86	2/33	<1/50	
Graminoids					
Agrostis gigantea	1/67	<1/14		2/25	
Bromopsis ciliata	2/100	<1/86	2/67	2/100	<1/67
Calamagrostis canadensis	<1/33	7/43			
Carex foenea	<1/33	1/29	5/50	1/25	
Glyceria striata		<1/14	<1/17	<1/25	
Poa fendleriana				<1/25	6/100
Poa pratensis	<1/33	2/86	22/100	11/100	38/100
Forbs					
Achillea millefolium	<1/67	2/100	2/100	<1/50	<1/33
Cardamine cordifolia	<1/33	<1/43	<1/33		<1/33
Disporum trachycarpum	<1/33	<1/29			
Equisetum arvense	<1/33	<1/43	1/17	2/75	<1/33
Erigeron eximius	2/100	2/14	8/50		
Fragaria americana	5/33	3/43	4/67	<1/75	<1/33
Fragaria ovalis	<1/67	1/86	1/83		<1/33
Galium triflorum	<1/100	3/71	2/33	4/100	8/67
Geranium caespitosum			1/33	<1/25	1/67
Geranium richardsonii	5/100	6/100	2/67	<1/75	
Heracleum sphondylium	4/100	2/57	<1/17	<1/75	
Hippochaete hyemalis		<1/29		1/25	1/33
Mertensia ciliata	3/100	<1/43	1/33		
Oreochrysum parryi	<1/67		<1/33		
Osmorhiza depauperata	3/100	2/86	<1/33	<1/50	
Pyrola asarifolia	<1/67	<1/29			
Rudbeckia laciniata		1/57	1/33	1/100	<1/33
Smilacina racemosa	<1/100	<1/29		<1/50	
Smilacina stellata	1/100	5/71	1/67	5/75	
Taraxacum officinale	<1/67	2/86	1/83	<1/50	<1/67
Thalictrum fendleri	7/100	<1/57	1/50	9/100	2/33
Viola canadensis	4/100	2/57	<1/67	<1/75	<1/67
Viola nephrophylla		<1/29	<1/17	<1/25	

APPENDIX 5

Mosaic Diagram of Selected Major Habitat Types of Northern New Mexico and Southern Colorado



DeVelice, Robert L., John A. Ludwig, William H. Moir, and Frank Ronco, Jr. 1986. A classification of forest habitat types of northern New Mexico and southern Colorado. USDA Forest Service General Technical Report RM–131, 59 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Forest habitat types in the mountains of northern New Mexico and southern Colorado were identified and described to develop an ecosystem classification. The final vegetation classification is based on 618 sample plots. A total of 8 climax series, 44 habitat types, and 12 phases of habitat types are defined. Keys and descriptions for each habitat type are provided. Soils and vegetation relationships, successional trends, management implications, tree productivity from site index, and relationships to other habitat type investigations in the Rocky Mountains are discussed.

Keywords: Forest vegetation, New Mexico, Colorado, habitat types, plant communities, plant associations, forest ecology, forest management

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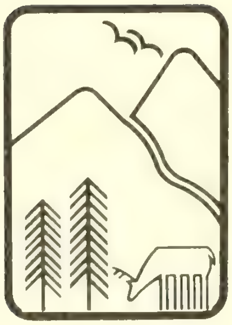
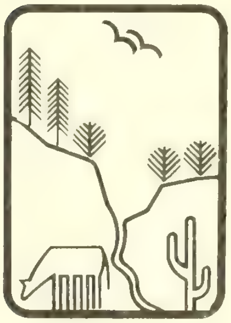


Rocky Mountains



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Rapid City, South Dakota
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*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-132**

User's Guide to RMTCM: Software for Travel Cost Analysis

Donald H. Rosenthal
Dennis M. Donnelly
Marie B. Schiffhauer
and
Glen E. Brink

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Abstract

RMTCM is an interactive menu-driven program for performing travel cost analysis. The program consists of four main modules: (1) data input; (2) data modification; (3) regression analysis; and (4) report writing. The report graphs the "second-stage" demand curve and estimates consumer surplus. The program is written in FORTRAN-V and a version is available for use on an IBM personal computer or compatible machine.

NOTE

The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any purpose other than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone other than a Government-produced computer program.

In general, there is no cost for this computer program. However, the requestor must provide a formatted standard double-sided, double-density "floppy" diskette, suitable for use in IBM personal computers (PC's) or compatibles; in addition, the requestor must arrange for shipping both ways, for example, enclosing with the request, a self-addressed, postage-paid mailer with suitable protection for the diskette. For further information write Valuation of Wildland Resource Benefits Research Work Unit, Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, 240 West Prospect Street, Fort Collins, CO 80526.

USDA Forest Service
General Technical Report RM-132

July 1986

User's Guide to RMTCM: Software for Travel Cost Analysis

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User's Guide to RMTCM: Software for Travel Cost Analysis

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INTRODUCTION

RMTCM (Rocky Mountain Station Travel Cost Model) is an interactive computer program to help build travel cost models. Travel cost models are used to estimate the dollar value of recreation sites. Building travel cost models involves several steps that are usually performed independently. The RMTCM program allows the user to perform the various steps in one integrated computer program.

This user's manual is designed to provide suggestions related to building a travel cost model (TCM). It does not give a conceptual overview of what the travel cost model is or when and what situations it should be applied to. Readers interested in a conceptual overview are referred to Dwyer et al. (1977), Rosenthal et al. (1984), or the U.S. Water Resources Council (1979).

RMTCM is designed for estimating single-site zonal travel cost models. However, it can also be used for individual observation based travel cost models. The way to do this is explained at the end of this publication. RMTCM cannot be used to estimate multiple-site or regional travel cost models. The body of this publication assumes the program is being used to estimate a single-site zonal TCM.

Efficient use of RMTCM requires a background in multiple regression analysis, an understanding of basic concepts in microeconomic theory, and some familiarity with travel cost analysis. Without this knowledge, parts of this publication may be difficult to understand, and the possibility of misapplication of the program increases markedly. Errors in one part of the program are likely to invalidate all of the results.

Although the TCM is an extremely useful tool for estimating the net economic benefit of a recreation site, as with any model, when the assumptions of the model are violated, the estimates of economic benefits can be wrong. The key assumptions are discussed in Dwyer et al. (1977) and Rosenthal et al. (1984). Users of the program are urged to make sure their models meet these assumptions.

The RMTCM program is currently resident on a Univac 1100/84 Computer at the U.S. Department of Agriculture Computer Center in Fort Collins, Colo., (FCCC). There is also a personal computer version of RMTCM that runs on an IBM[3] personal computer or compatible machine. The FCCC version and the personal computer versions of RMTCM are identical, except for the operating systems of the host computers.

Persons desiring a copy of the personal computer version of RMTCM may write to the authors requesting a copy and enclosing a blank formatted floppy diskette. The RMTCM program is written and compiled in ANSI standard FORTRAN-V. The personal computer version diskette contains three files: (1) a "READ.ME" file containing general information; (2) a "RMTCM.EXE" file containing the executable RMTCM file; and (3) a "TABLE1" file containing a test data set.

Before using the program, the reader is advised to review the entire user's manual. In particular, the sections on data collection and preparation should be thoroughly understood before using RMTCM.

ACCESSING RMTCM

USING RMTCM AT THE FORT COLLINS COMPUTER CENTER (FCCC)

The first step in using RMTCM is to log on to the FCCC computer. If the reader does not know how to log onto the FCCC computer, then speak to a computer specialist or call the FCCC (303–224–1510). It is recommended that <CTRL>H (i.e., depress and hold the control key and then press H) be designated as a destructive backspace during the log-on procedure. Also recommended is that the user specify a project identification abbreviation (proj. id.) other than "RM" on the @RUN statement to avoid possible file conflicts among multiple users. An example is @RUN RUNID, ACCT.NO., MY-PROJ-ID

Once the user is logged onto FCCC one of two states will exist. Either the RMTCM program is on disk file and ready for use, or it must "rolled in" from tape before it can be used. To see if it is on disk, enter the command: @ADD RM*TCM.RUN <CR> from your terminal. If the terminal responds

ENTER OPTION (0 FOR HELP) then the RMTCM program has been loaded and is ready for use. If the terminal responds that it is unable to find the file, then it must be mounted from tape before it can be used. To mount the tape enter the following commands:

```
@ASG,T RM*TCM-TAPE.,U9S,F32498      <CR>
@ASG,UP RM*TCM.                     <CR>
@COPY,G RM*TCM-TAPE.,RM*TCM.        <CR>
@FREE RM*TCM-TAPE.                  <CR>
@FREE RM*TCM.                       <CR>
@SAVE RM*TCM.,yymmdd                <CR>
TRAVEL COST MODEL                   <CR>
@ADD RM*TCM.RUN                     <CR>
```

The "yymmdd" command on the sixth line refers to the year, month, and day when the RMTCM file will be purged from an account. For example, typing 860331 will result in the file being saved on an account number until March 31, 1986. After entering this sequence of commands, the terminal should respond with:

---

[3] *The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U. S. Department of Agriculture to the exclusion of others that may be suitable.*

```
ENTER OPTION (0 FOR HELP)?
```

As the RMTCM program is executing, output will be generated at the terminal. Simultaneously, all the output appearing on the terminal will be echoed to a disk file. When the user exits RMTCM, a permanent file will be saved automatically at the FCCC on the account that accessed RMTCM. The contents of that permanent file are exactly what appeared at the terminal during the RMTCM session. Users working with a CRT screen can get a printed copy of the RMTCM session by routing the permanent file to the printer.

The name of the file that is automatically created when running RMTCM is "MY-PROJ-ID*TCM-LOG.". Unless specified otherwise, that file will be saved for 6 days. If during that six-day period RMTCM is run again, the old copy of the "MY-PROJ-ID*TCM-LOG." file will be replaced by an updated version. That updated version will be saved only until the 6-day period for the original "MY-PROJ-ID*TCM-LOG." file expires. To change the expiration date, enter:

```
@SAVE MY-PROJ-ID*TCM-LOG.,yymmdd
```

from the terminal after exiting RMTCM but before logging off the Univac.

Ordinarily, it will not be necessary to save "MY-PROJ-ID*TCM-LOG." for very long. If the terminal was printing while RMTCM was running the file is already printed. To print the file, enter one of the following two sets of commands after exiting RMTCM.

1) To send to a batch site:

```
@FREE TCM-LOG
@SYM,U MY-PROJ-ID*TCM-LOG.,,xxxxxx    <CR>
    (where xxxxxx = batch site id).
```

2) To send to a demand terminal for printing after the @FIN statement:

```
@SYM,U MY-PROJ-ID*TCM-LOG.,, yyyyy/U  <CR>
    (where yyyyy = user id)
@FIN                                  <CR>
@@SEND,U                              <CR>.
```

USING RMTCM ON A PERSONAL COMPUTER

The best way to use RMTCM depends on whether the personal computer has a hard disk or floppy disk(s). With a hard disk system, copy the "RMTCM.EXE" file from the floppy to the hard disk. Then make the hard drive and the directory where the "RMTCM.EXE" file is located the default drive and directory. At this point start the program by typing "RMTCM" followed by a carriage return.

With a two-floppy disk system, make drive B the default drive and place the diskette containing "RMTCM.EXE" in drive A. Place a formatted diskette in drive B and then start the program by typing "A:RMTCM" followed by a carriage return. On a one-floppy system, insert the diskette and start the program by typing "RMTCM." To run RMTCM with the test data set, copy the file "TABLE1" to the default drive.

When RMTCM is running, it will read files from and write files to the default drive and default directory. With a one-floppy system the data and program must be on the same diskette. If the user wants to read a data file from other than the default drive and directory, then a valid drive and path specification must be given. The same follows for writing files. For example, to read a data file named "RMTCM.DAT" from the "INPUT" directory of the A drive the user should type "A:\INPUT\RMTCM.DAT" when asked for the name of the input data file.

As RMTCM is executing the regression portion of the program, it temporarily writes the user's data file to a disk drive and then re-reads it once the regression is complete. This is done to conserve memory. The temporary file is written to the default drive and default directory. There is no way to alter this. User's should make sure there is enough storage space on the default drive and directory to accommodate this temporary file.

RMTCM can read only ASCII files with numeric data. If such a file is printed it will look "normal" and contain only numbers, decimal points, negative signs, positive signs, and blanks (or commas). RMTCM will not read .DIF files or .WKS files.

The simplest way to create an ASCII file is to use a wordprocessing program in non-document (ASCII) mode or a full-screen editor. Alternatively, ASCII files can be formed using the EDLIN feature of PC-DOS or MS-DOS. Some spreadsheet programs, such as Lotus 1–2–3[3], will write ASCII files if the user routes a print file to an output file. On Lotus 1–2–3 , be sure to specify "unformatted" output to avoid page breaks in the data set. An advantage of using a spreadsheet program is that the user can do all the data transformations inside the spreadsheet. Very complex data transformations can be done with a spreadsheet program. The transformed data then can be written as an ASCII file and subsequently used as input for RMTCM.

USING THE RMTCM PROGRAM

DATA COLLECTION

It is useful to distinguish between the different types of data that are needed for travel cost analysis. For RMTCM, data can be classified as either primary or secondary, and also as essential or nonessential. The four types of data that are used in RMTCM and the specific variables associated with each type are as follows.

Data Usable by RMTCM

Type 1: Primary, Essential
- . where visitors to the site came from

Type 2: Secondary, Essential
- . price of a trip
  - .. distance
  - .. cost per mile
  - .. persons per vehicle
  - .. average travel speed
  - .. per-capita income to figure opportunity cost of time
  - .. entry fee

- trips per-capita
  - trips from each origin
  - sampling rate[4]
  - population of origin

Type 3: Primary, Non-essential
- length of stay
- single versus multiple destination trips

Type 4: Secondary, Non-essential
- substitute recreation areas
  - imperfect substitutes
  - perfect substitutes
- demographic characteristics of origins.

Type 1 Data: Primary, Essential

Primary data refers to data that must be collected about persons using the recreation site being modeled. Essential data refers to data needed to make estimating a travel cost model mathematically possible. In the RMTCM program, there is only one primary and essential piece of data: the city and/or county where the recreationists who visited the site began their trip. One of the main reasons for the widespread use of the TCM is that it can be run with a minimal amount of information.

A good way to estimate where a group began its trip is to determine the zip code of its home. A better way is to directly ask for the city and county of residence. The latter method is preferable, because zip codes must be converted to cities and counties during the data preparation steps. Also, zip code boundaries do not always correspond with city and county boundaries. Information on home zip codes often is contained in visitor registration forms.

Type 2 Data: Secondary, Essential

In the zonal TCM the per-capita visitation rate of zones of origins is regressed on, as a minimum, the price of a trip to the recreation site. To use RMTCM, type 1 data must be combined with secondary information in order to calculate the value of the independent (price) and dependent (visits per-capita) variables for each zone of origin.

To calculate trips per-capita, it is necessary to form a number of zones of origin around the recreation site. Zones of origin can be defined as concentric rings around the recreation site (Clawson and Knetsch 1966, Sutherland 1982) or individual units of population located around the site. The least amount of aggregation is desirable. In practice, zones of origin are most easily defined as counties or aggregations of counties. Using individual counties is preferable to concentric rings because two counties located the same distance from the study site, for a variety of reasons, might have different visitation rates. If concentric rings were used, the two counties would be averaged into one large origin, and information would be lost. Forming origins is discussed in more detail later.

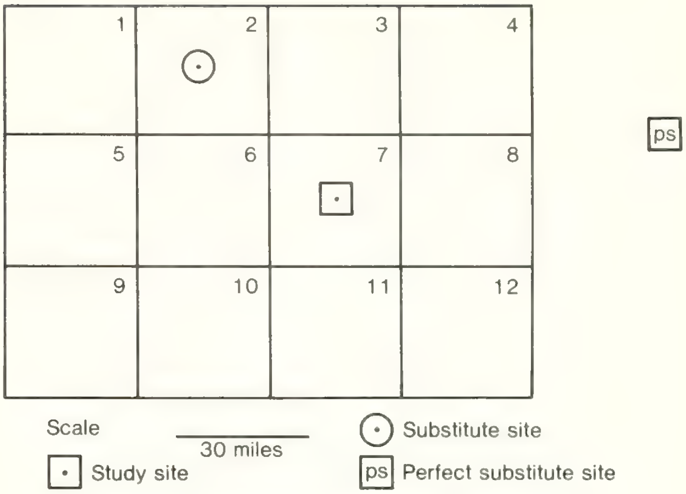

Figure 1.—Location of origins and study sites.

Figure 1 shows a hypothetical study site and 12 zones of origin around the site. Once the origins are defined, the type 1 information about where visitors came from can be used to determine the number of trips originating in each zone. The number of trips from each zone divided by the population of each zone (available from census data) is trips per capita.

Usually only a fraction of the trips to a recreation site are sampled. Therefore, the number of trips sampled from each zone must be multiplied by the inverse of the sampling rate to estimate the total number of trips from a zone of origin. If the sampling rate is not known, RMTCM can still be run using only the sampled trips. In this case, the consumer surplus per trip figure for the site will be valid, but the total consumer surplus for the site will be unknown. Consumer surplus is defined as the amount recreationists are willing to pay, in excess of existing costs, for the right to visit the study recreation site.

The per-person price of a round-trip from an origin $i (i = 1,n)$ to the recreation site is defined as

$$P_i = \frac{(d_i)(a)(b)}{e} + \frac{(d_i)(a)(t)}{c} + \frac{f}{e} \qquad [1]$$

where: P_i = per-person dollar cost of a round-trip from the origin to the recreation site;
d_i = distance from the ith origin to the recreation site;
a = 1 if d is the round-trip distance, or 2 if d is the one-way distance;
b = variable operating cost, in dollars per mile, for a vehicle (usually in the range of $0.1 to $0.25);
e = average number of persons per vehicle;
t = hourly opportunity cost of travel time (recommend using 25–50% of the average hourly wage rate);
c = average travel speed in miles per hour; and
f = per vehicle entry fee at the site.

The first term on the right side of eq. [1] represents the out-of-pocket costs of driving a car from an origin to the recreation site and returning. This out-of-pocket cost is the number of miles traveled multiplied by the variable cost per mile of operating a vehicle. Fixed costs, such as insurance payments or interest charges, are not considered. Information on the cost of operating an automobile can be obtained from the U.S. Department of Transportation (1984). The total vehicle operating dollar cost is then divided by the average number of persons per vehicle. The cost should be expressed on a per person basis in order to be consistent with the trips per capita measure used for the dependent variable. In 1984, the average variable cost of operating a vehicle was about 12 cents per mile (i.e., $b = \$0.12$) (U.S. Department of Transportation 1984).

---

[4] *Essential to estimate total consumer surplus, but not essential to estimate consumer surplus per trip.*

Do not use the average traveling costs reported by persons contacted at the recreation site. With the zonal TCM, the traveling cost used must be the average of all persons living in an origin, not just those who visited the site. Visitors may have a different perception of cost than non-visitors.

The second term on the right side of eq. [1] represents the time cost of a trip. The reasoning behind this term is that time spent traveling also is a cost. Empirical studies of commuters indicate that people value their travel time at between 25% and 50% of their hourly wage rate (Cesario 1976). However, other research has shown that recreationists may value their travel time at the full wage rate (Smith et al. 1983). The correct figure to use for the opportunity cost of time is the subject of continuing research.

For RMTCM, the recommended opportunity cost of time is 50% of the hourly wage rate. The average hourly wage rate of a person living in an origin can be estimated by dividing average per-capita income by 2,080, the typical number of hours in a work year. Because per-capita income includes earned and unearned income, this estimate will somewhat overstate the hourly wage rate. Dividing the reciprocal of 2,080 by 2 equals 0.00024038. Therefore, multiplying the average per-capita income by 0.00024038 is equal to using 50% of the hourly wage rate (as estimated by per-capita income) as the opportunity cost of travel time. The second term on the right side of eq. [1] multiplies this hourly opportunity cost of travel time by the number of hours spent in travel.

The third term on the right side of eq. [1] represents the per-person entry fee to the site. The sum of the time cost, the out-of-pocket vehicle operating cost, and entry cost equals the per-person cost of a trip to the recreation site. To calculate price, information on d_i, a, b, t, f, c, and e is needed.

Type 3 Data: Primary, Non-essential

Two pieces of information that fall into this category: (1) the length of time on site for each trip to the recreation site; and (2) whether or not the recreation site was the only destination on the trip or one of several destinations. Time-on-site information is useful for two reasons. First, knowing this allows the analyst to express economic value on a per unit time basis (e.g., dollars per recreation visitor day). Second, the TCM assumes that the average time-on-site is the same for all origins. With time-on-site information, this assumption can be tested. If the assumption is severely violated, the data set can be segmented into separate data sets having homogeneous lengths of stay (e.g., split the data by day users versus overnight users).

In the TCM, only recreationists on single destination trips should be included in the analysis. For example, if a person left home and visited three recreation sites, one of which is the site being analyzed via travel cost analysis, then that person's trip should not be included as part of the data set. Only persons who left their residences, went to the study site and went directly back home should be included as data in the TCM.

Multiple destination recreationists are excluded from the analysis, because allocating a portion of their total trip costs to a specific recreation site is difficult. This is a shortcoming of the TCM. Excluding multiple destination recreationists from the data set is not the ideal solution, but it is the most reasonable one available at this time.

When there is no information on whether or not trips are multiple destination, then reasoned judgement must be used. Usually, most trips coming from within a certain distance radius will be single destination trips. A unique and scenic natural area might draw single destination visitors from as far away as 2,000 miles. In contrast, a local recreation area might only draw visitors from an area of 50 miles.

Type 4 Data: Secondary, Non-essential

In its most general form, the TCM models the number of trips per-capita from an origin as

$$VC_i = f(P_i, S_i, D_i) \qquad [2]$$

where: VC_i = trips per-capita from origin i;
P_i = price per-person per-trip to the recreation site from origin i;
S_i = a measure(s) of substitute recreation areas available to origin i; and
D_i = demographic characteristics of origin i.

Although the type 4 information is not required by RMTCM, gathering such information will greatly enhance the validity of the estimated model.

The number of trips per capita from an origin to a recreation site will be influenced by the number of alternative recreation sites offering similar recreation opportunities. When discussing substitute recreation sites, a distinction must be drawn between a perfect substitute recreation site and an imperfect substitute site. In RMTCM, for an alternative destination to be considered as a perfect substitute site, two conditions must be met: (1) the quality of the alternative site must equal or exceed the study site in all respects; and (2) there must be enough excess capacity at the alternative site so that the increased use that would occur at that site in the event of the closure of the study site would not deteriorate the quality enough to violate the first condition. Alternative sites that do not meet these two conditions are imperfect substitute sites. Perfect and imperfect substitute sites are handled differently by RMTCM.

It is not always clear what recreation sites to consider as substitutes. The simplicity of the hypothetical data shown in figure 1 is unlikely when using actual data. A few guidelines might be helpful. First, a substitute recreation site is an area where users of the study recreation site might go if the study site was no longer available for recreation. Second, there may be many substitutes to the study site. The effect of all of these substitute areas needs to be considered. Of primary importance are those offering similar recreation opportunities. One good way to reflect the influence of substitutes is to record the distance from each origin to each substitute recreation site (Burt and Brewer 1971, Cicchetti et al. 1975). Then, all the imperfect substitute distances should be entered as predictor variables in the estimated demand curve. Another way to handle multiple imperfect substitutes is to construct one or more indexes that reflect(s) the degree of substitution possibilities available to each origin (Knetsch et al. 1976).

In figure 1, the market area is the solid rectangle enclosing the 12 origins. Most trips to the study site are drawn from within the market area. Substitute recreation sites outside of the market area are as important to the TCM as substitute sites inside the market area. A natural question is just how far outside the market area should be considered. For example, when building a travel cost model in Colorado, do substitute recreation sites in California need to be considered? There is no clear answer to this question. As a guide, find the origin within the market area that is the greatest distance from the study site. In figure 1 this distance is 67 miles. Any substitute recreation sites that are within 67 miles of the market area boundary should be considered for inclusion in the TCM. Taking the network of substitute recreation sites into account is a very important part of building a TCM.

If one or more perfect substitute sites are identified, then the price (distance) of a trip from each origin to the closest perfect substitute site should be recorded. However, this price should not be entered into the demand equation in the same manner as imperfect substitute prices. Instead, the price of the perfect substitute site should be used to truncate the demand curve (Knetsch 1977). Quite simply, the price of a perfect substitute site places an upper bound on the willingness of a person to pay for the right to enter the study site. RMTCM has an option for truncating the demand curve. If the user is not sure if a site is a perfect substitute or imperfect substitute, the analysis can be easily run both ways in RMTCM.

The characteristics of an origin also may influence its per-capita visitation rate. Variables to consider including in the the demand curve are per-capita income, average age, average education, and anything else that might be related to visitation rates. Per-capita income is particularly important to consider, because economic theory indicates income is an argument in a demand function.

DATA PREPARATION

The data preparation step is most easily explained with an example. Consider the layout of origin and recreation sites shown in figure 1. The recreation site for which a TCM will be developed here, is in origin number 7. An imperfect substitute recreation site is shown in origin number 2. A perfect substitute site is shown on the far right side of figure 1. For the moment, the perfect substitute site will be ignored.

The main function of the data preparation step is to organize the information so that it can be used by RMTCM. Table 1 shows a simple way to organize the data needed by RMTCM. For each origin, the analyst will have gathered information on the population, per-capita income, the distance from each origin center to the study site, distance to the substitute site(s), and the number of trips from each origin to the study site. Table 1 shows it is 67 miles from origin 1 to the study site, 30 miles to the substitute site, and 136 miles to the perfect substitute site. Figure 1 distances were measured using a ruler. Actual distances should represent the driving distance between the origin center and the destinations. The origin center can be defined as either the point of a large centrally located city in the origin, or by using published information concerning the latitude and longitude of the population weighted center of each county in the United States (U.S. Bureau of Census 1974).

Table 1 lists the number of trips coming from each origin to the study site. Origin 1 delivered 224 trips to the study site in origin 7. A car with two persons visiting the site represents two trips. Customarily it is assumed that the number of persons per vehicle is constant across origins. The trips shown in table 1 have been expanded by a sampling fraction. If 10% of the trips to the study site were sampled, then only 22.4 trips from origin 1 to the study site would actually have been recorded.

DATA INPUT

When the data are entered into RMTCM, the program will prompt the user with a series of questions (fig. 2). The data collection and data preparation steps are the hardest part of building a travel cost model. The data input process consists of entering the information from table 1 into the RMTCM program. This is the time to begin the RMTCM program. The Appendix displays an RMTCM run in which an external ASCII file is used for data input.

The first prompt from the RMTCM program will be a short introductory statement succeeded by this message:

```
ENTER OPTION (0 FOR HELP)
?
```

If a "0" is entered (do not type the quotation marks), the following will be listed.

```
1) INPUT DATA
2) DISTANCE TO COST CONVERSION
3) MODIFY DATA
```

```
4) RUN REGRESSIONS AND REPORTS
5) EXIT RMTCM PROGRAM
ENTER OPTION (0 FOR HELP)
?
```

RMTCM is a menu-driven program. At each step, it prompts the user for the appropriate response. The five options above are the main menu. Throughout the RMTCM program, the main menu will be relisted. Users are free to jump between steps 2, 3 and 4 in any order. The normal progression through RMTCM is 1, 2, 3, 4, and 5, in order.

When entering data, enter a 1 in response to the main menu. The following prompt

```
1) INPUT DATA INTERACTIVELY FROM
   KEYBOARD
2) READ AN EXTERNAL ASCII DATA FILE
3) READ A PREVIOUSLY CREATED RMTCM
   SYSTEM FILE
4) RETURN TO MAIN MENU
   CHOOSE FORM OF DATA ENTRY (1, 2, 3, or 4)
?
```

will be displayed. There are three options for loading data into RMTCM. Do not read data into the program twice during one RMTCM session. If the user is familiar with how to set up ASCII data files on the computer, that is the easiest option. If the data are input interactively

Table 1.—Data ready for input into RMTCM.

				Distance To			
Origin Number	**Population[1]**	**Visits[1,2]**	**PCI[3]**	**Study[1] Site**	**Substitute Site**	**Perfect Substitute**	**Other Variables**
1	30000	224	8000	67	30	136	-
2	9000	69	7000	42	1	106	-
3	6000	77	8100	30	30	76	-
4	9000	110	7900	42	60	47	-
5	30000	282	8800	60	42	136	-
6	12000	141	7300	30	30	106	-
7	4000	87	9100	1	42	76	-
8	12000	202	8150	30	67	47	-
9	40000	356	7700	67	67	142	-
10	3000	35	7000	42	60	114	-
11	6000	93	8100	30	67	87	-
12	14000	195	7375	42	85	64	-

[1] *Variable is required in order for RMTCM to execute.*
[2] *Visits have been expanded by the inverse of the sampling fraction.*
[3] *Per-capita income.*

Method of Data Input: Select one
1) Input data interactively from keyboard
2) Read an external ASCII data file
3) Read a previously created RMTCM system file

Name of Data File (not applicable for keyboard input): ____________________
Number of Variables per Case ____________
Variable Names (0–8 characters)

Program Generated Name	User Name	Description
C1	POP	origin population
C2	VISIT	number trips
C3	PCI	per-capita income
C4	DIS	distance to study site
C5	DSUB	distance to substitute
C6	DPER	distance to perfect substitute
C7	______	____________
C8	______	____________

Input format for external file (default is free field, each case starts on new line)
(____________________)

Missing Value Indicator (use negative integer, such as -999): ____________

Figure 2.—Data input information.

at the terminal, it must be done without mistakes. There is no facility for correcting typos in RMTCM apart from a destructive backspace or entering a new column of data in the modify data option (see "Modify Data"). Interactive data entry only should be used on small data sets. The third option is used to reanalyze a previously created RMTCM system file.

Options 1 and 2

If option 2 was selected, the prompt

```
ENTER ASCII DATA FILE NAME
?
```

will ask for the location of the user's data file. Enter the name of the data file. The data file must be ASCII; RMTCM cannot read binary or EBCDIC files.

If option 1 was selected or the option 2 ASCII data file was successfully read, the program will display

```
ENTER NUMBER OF VARIABLES
?
```

The number of variables is equal to the number of data points being entered for each origin. In table 1 there are six variables. In that case, enter a 6 followed by a carriage return. The terminal will respond with:

```
MAXIMUM NUMBER OF CASES IS nnnn
NAME VARIABLES (0–8 CHARACTERS)
C1
ENTER NAME
?
```

This message gives three pieces of information. First, the program displays the maximum size of the data set that it can accommodate with the number of variables the user has indicated in the preceding step. The program is dimensioned to handle data sets of only a certain size. The size of the data set is determined by multiplying the number of variables times the number of cases. On the personal computer and FCCC versions, the maximum of this product is approximately 4,000. Additionally, RMTCM can handle a maximum of 20 variables. After displaying the data set size limitations, the program automatically feeds into the next step, naming the variables.

Each variable is automatically assigned the name Cnn, where nn is the column number. In the example data set shown in table 1, C1 refers to the population column, and C6 refers to the distance to perfect substitute column (see the sample output in the Appendix). The label can be from 0 to 8 characters. Each variable will have the name assigned to it and the default name associated with it. It is not necessary to name a variable; but it does help interpret the output. Both the default name (i.e., Cnn) and the assigned name can be used interchangeably in subsequent stages of RMTCM. The terminal will prompt for a variable name for each variable in the data set.

The next prompt depends on whether option 1 or 2 was selected. If 1 was selected,

```
TERMINAL INPUT IS FREE FORMAT. USES AS
MANY LINES AS REQUIRED FOR EACH CASE,
BUT EACH CASE M U S T BEGIN ON A NEW LINE.
ENTER "END" TO STOP DATA INPUT.
ENTER DATA NOW.
```

will be displayed. Enter data across each row with a space between each variable. At the end of each row's worth of data, enter a carriage return. The data for each origin must begin on a new line. If the data for an origin take up more than one line, enter a carriage return and continue that origin's data on the next line. Be sure to begin the data for a new origin on a new line. If there is missing information for a variable (e.g., per capita income for an origin is unknown) enter an integer that can be declared later as a missing value code. Negative integers work well, because they will not be confused with nonmissing data.

To terminate data input push carriage return to get on a new line, then enter an "E" (do not type quotations) followed by another carriage return.

If option 2 was selected, the prompt

```
SPECIFY INPUT FORMAT (Y OR N)
?
```

will ask if an format statement is going to be provided by the user. An "N" followed by a carriage return (alternatively omit the "N" and simply hit carriage return; for all yes-no questions "N" is assumed unless "Y" is entered) invokes the default format. The default format is free-field. Each data point must be separated by a blank and each origin must begin on a new record. If "Y" is entered, the prompt

```
ENTER FORMAT
?
```

will ask for the input format. The user should enter a valid F-type FORTRAN-V format statement including left and right parentheses (but not the word "format"). For example, the following is a valid response to the format query (do not type the quotations), "(4F2.0,3F6.2)". No syntax checking is performed on the format statement, and an execution error will result if it is not correct.

With either option 1 or 2, after all the data has been read, the message

```
NUMBER OF CASES READ = x
FIRST FOUR LINES OF DATA ARE AS FOLLOWS...
  [data for first four origins listed]
LAST LINE OF DATA IS AS FOLLOWS...
  [data for last origin listed]
LIST ALL THE DATA      (Y OR N)
?
```

verifies the number of cases read, lists the first four cases and the last, and asks if all the data are to be listed. Listing all the data helps verify that everything was read properly. Large or small data points will be listed using exponential notation. The sign and size of the exponent are displayed to the right of the letter E. For example, 0.13829E06 is equal to 138,290 and –0.13829E–02 is –0.0013829.

After the data listing prompt, the following prompt:

```
SUBSTITUTE MEANS FOR MISSING VALUES?
(Y OR N)
?
```

will appear. Missing data can be replaced by the mean of that variable for cases on which the data is not missing. Users are urged to avoid having any missing data. It is especially important not to have any of the trip information missing. Nevertheless, many times missing data are unavoidable. If "N" is given, the main menu will be relisted. A "Y" response to this query results in

```
ENTER MISSING DATA VALUE (NUMERIC)
?
```

being displayed. The numeric value must be an integer. Every occurrence of this integer will be replaced by the mean of the corresponding nonmissing data. A number such as –999 is good, because it will not be mistaken for valid data. The mean then will be used in all subsequent statistical analyses.

Option 3

Option 3 is used to read a previously created RMTCM system file. When the user exits RMTCM, an option of saving the data file and associated variable names is given. If that option is selected, an RMTCM system file will exist with the name assigned by the user.

To use this file, select option 3 from input menu and answer this prompt.

```
ENTER NAME OF RMTCM SYSTEM FILE
?
```

Enter the name of the data file followed by a carriage return. After the file is read, summary information about the file will be printed and an option to list all the data will be given.

DISTANCE TO COST CONVERSION

After the missing values questions have been answered, the program will redisplay the main menu. Entering a 2 causes a series of self explanatory questions to appear. The questions give RMTCM the information it needs to calculate eq. [1]. Figure 3 is a worksheet summarizing the information needed at this stage of the analysis.

Two points should be made about converting distances to cost. First, any opportunity cost of time can be used, including zero. Second, if the user wants to use another formula to convert distances to cost, this can be done before entering the program or by using the modify data option.

After the user has answered the six questions related to the distance to cost conversion calculations (see the Appendix for listing of questions), the following prompt

```
ENTER NAME OF VARIABLE TO CONVERT
?
```

is displayed. This prompt asks for the name of the distance variable being converted to cost. For the example data in table 1, C4, or whatever name it was given in the name variable process, would be typed in. The distance to cost formula is then applied to each case for C4. The value of C4 represents d_i in the distance-to-cost formula.

A. Average travel speed 50 MPH
B. Vehicle cost per mile 0.12 $/mile
C. Persons per vehicle 2.5
D. Are distances one-way (0) or round trip (R) 0
E. Cost of time 1.89 $/hour
F. Per vehicle entry fee 0 $/vehicle

G. Variables to Convert	New Name
DIS (C4)	COST
DSUB (C5)	SUBCOST
DPER (C6)	PERCOST

Figure 3.—Worksheet for distance to cost conversion.

The resulting cost data does not replace the distance data but is added as a new column of data. The prompt

```
ENTER NAME FOR NEW VARIABLE (Cnn)
?
```

asks for the name of the new variable. After naming the cost variable, the first four cases will be listed. Then the prompt

```
LIST ALL THE COST VALUES (Y OR N)
?
```

asks if all the cases are to be listed. The data will be listed in three columns with the case number, the distance data, and the cost data on each line.

If another distance variable is to be converted with the same parameter values (i.e., a, b, e, t, c, and f), enter "Y" when:

```
ANOTHER, WITH THE SAME VALUES (Y OR N)
?
```

appears at the terminal. If none of the parameters need to be changed or there are no other variables to convert, simply enter a carriage return (for all yes/no prompts, a carriage return defaults to no), and the program will return to the main menu.

MODIFY DATA

The modify option allows data transformations, thereby enabling the use of five different functional forms in RMTCM. The user must perform the transformations required to fit the different functional forms; it is not done automatically. These different functional forms are discussed in the next section. It is necessary to divide visits by population in order to calculate visits per capita. The modify data option also can be used to enter a new column of data as a replacement for a column that has an error in it.

Modify data is one of the options on the main RMTCM menu. After entering a 3 while in the main menu, the following prompt

```
 0) RELIST MENU
 1) ADD TWO COLUMNS (SEE ALSO OPTION 9)
 2) SUBTRACT (FIRST - SECOND)
 3) MULTIPLY (FIRST * SECOND)
 4) DIVIDE (FIRST/SECOND)
 5) MULTIPLY (COLUMN*CONSTANT)
 6) POWER (COLUMN**CONSTANT)
 7) NATURAL LOGARITHM
 8) ENTER NEW COLUMN OF DATA
 9) ADD A CONSTANT TO A COLUMN
10) EXIT TO MAIN MENU
 ENTER MODIFY CHOICE
 ?
```

will appear. The modify menu has 11 options. To relist the menu when you are in the middle of the modify process, simply enter 0 followed by a carriage return.

All of the operations in the modify menu, except 0, 8 and 10, act on the entire column(s) of data. Choices 1, 2, 3, and 4 require two columns of input data. Choices 5, 6, 7, and 9 require only one input column name. Choice 8, entering a new column of data, requires no input column. In all cases an output column must be specified. The output column can be an existing column or it can be a new column. If the output column is an existing column, the data in that column will be overwritten by the modified data. If the modified data are written on a new column (much better) the new variable will be added to the RMTCM data set. Sometimes it could be useful to overwrite an existing column to avoid exceeding the 20 variable maximum.

After selecting the modify choice and answering the appropriate questions, the following prompt will appear:

```
PUT RESULT IN EXISTING COLUMN (Y OR N)
?
```

If "N" is given, RMTCM will ask for the name of the new output column. After naming the new output column, the first four and last cases in the data set are listed. Then a prompt asks if all the data are to be listed. When the data modifications are complete, press 10 to return to the main RMTCM menu.

The Appendix gives an example of using the modify data option to compute visits per-capita.

FITTING A MODEL

Building a travel cost model has been divided into seven separate steps in this publication. The last two steps, fitting a model and report writing, are both combined in the run regression and reports option in the main RMTCM menu. Before entering this option, all the data needed for the travel cost model should be available. If all the data and the necessary transformations are not available, return to the modify data option. Before describing how the program actually works, an overview may be helpful.

Functional Forms

The RMTCM program uses multiple regression to analyze TCMs with five different functional forms. These functional forms are: (1) linear, (2) quadratic, (3) semi-log (independent), (4) semi-log (dependent), and (5) double-log. The best functional form to use in a TCM depends on the particular data set.

Past experience with the TCM suggests that either the semi-log (log-dependent) or double-log functional forms are the best suited in most cases. To fit these functional forms, the data must be transformed in the appropriate manner (much like any regression program) before fitting the regression. Good texts on multiple regression and data transformations in multiple regression include Draper and Smith (1966) and Kmenta (1971). To run RMTCM, regardless of which functional form is used, one column of data must represent the cost of the trip from the origin to the study site (the logarithm of cost is not good enough), and another column must show the population of each origin. The information on cost and population is needed to generate the RMTCM reports. The cost and population variable must be present in the data set, but need not be included in the regression itself.

The five functional forms are as follows;

Linear
$$VC_i = B_0 + B_1C_i + B_2Z_{i1} + B_3Z_{i2} + \ldots + B_mZ_{iz} + \epsilon_i$$

Quadratic
$$VC_i = B_0 + B_1C_i + B_2C_i^2 + B_3Z_{i1} + \ldots + B_mZ_{iz} + \epsilon_i$$

Semi-Log Independent
$$VC_i = B_0 + B_1Ln(C_i) + B_2Z_{i1} + \ldots + B_mZ_{iz} + \epsilon_i$$

Semi-Log Dependent
$$Ln(VC_i) = B_0 + B_1C_i + B_2Z_{i1} + \ldots + B_mZ_{iz} + \epsilon_i$$

Double-Log
$$Ln(VC_i) = B_0 + B_1Ln(C_i) + B_2Z_{i1} + \ldots + B_mZ_{iz} + \epsilon_i$$

where VC_i = trips per-capita, i.e., visits/population from origin i(i = 1,n)
B_j = regression coefficients (j = 0...m) to be estimated by RMTCM
C_i = per-person cost of a round-trip from origin i to the site
Z_{ik} = other predictor variables used in the models (k = 1,z), usually per-capita income and the cost of substitute sites
ϵ_i = an error term, and
Ln( ) = natural logarithm of variable in parentheses.

Each of these functional forms is a different way of representing the relationship between trips per-capita from an origin to the study site.

The Z_{ik} terms are perfectly flexible. For example, in the linear functional form it is possible for one of the Z_{ik}'s to be the logarithm of per-capita income and another to be the squared average age of an origin. The one limitation is that Z_{ik} cannot be a function of C_i. In other words, changing C_i should not change the value of any Z_{ik} terms. The Z_{ik} terms customarily include the price(s) of substitute sites, per-capita income, and other measures about the characteristics of the origins such as average age, education level, etc. Despite the flexibility of RMTCM, these five functional forms are customarily used in a relatively standard way. Graphs of the five functional forms are shown in figures 4 and 5.

Linear

This functional form was popular in earlier TCMs mainly because of its simplicity. With a linear functional form the per-capita visitation rate is regressed on the cost of traveling from an origin to the site and other characteristics of the origin. The Z_{ik} terms usually are not transformed. For example, per-capita income usually is used instead of the log of per-capita income. However, RMTCM will work either way. Most empirical work shows that the linear function form does not fit travel cost data very well.

Quadratic

The quadratic functional form is identical to the linear functional form with the exception that a squared term of the cost of traveling from an origin to the site has been added. The quadratic form is much superior to the linear functional form for most applied travel cost models. The squared term on cost allows the estimated demand curve to bend. When using the quadratic functional form some cautions should be noted. The program assumes the B_1 coefficient is negative and the B_2 coefficient is positive. If the coefficients estimated do not have these signs, then get expert help or use a different functional form.

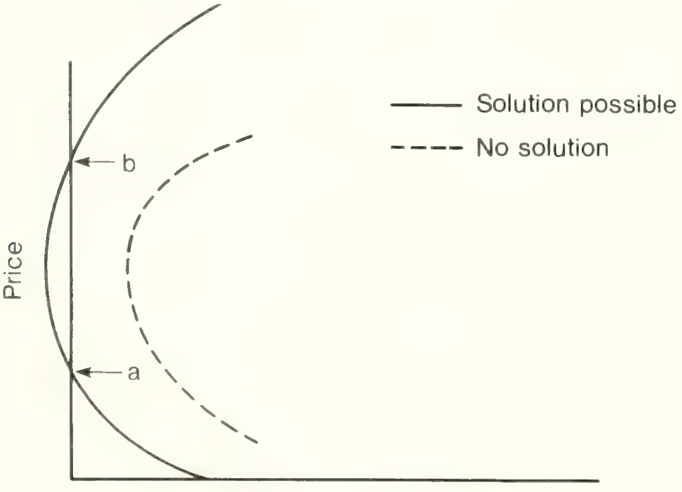

Figure 4.—The quadratic functional form.

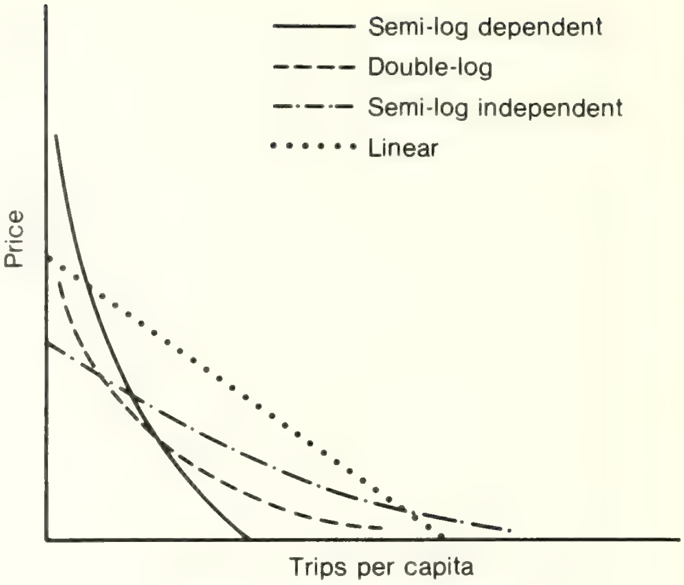

Figure 5.—Four functional forms.

A further problem with the quadratic functional form is that it may never predict zero visitation regardless of the fee imposed at the recreation site. Figure 4 graphs a quadratic functional form. To generate reports, the RMTCM program solves for the point labeled "a" on figure 4. That is, the cost at which zero trips from an origin will be predicted. In most cases there will be two solutions, point "a" and point "b." The RMTCM program uses only point "a". However, from some data the multiple regression program in RMTCM might fit a curve that looks like the dashed line in figure 4. In such a case, the curve bends backwards and upwards before trips per-capita is driven to zero. In other words, there is no finite fee increase that will result in zero predicted visitation. This is an unreasonable model, and RMTCM will inform the user of such a problem. Despite the cautions noted for the quadratic functional form, it can be quite useful in a number of applied studies.

Semi-log (Independent)

Like the quadratic form, the semi-log independent form also has been found to be useful in travel cost analysis. The semi-log independent form is shown in figure 5. It is asymptotic to the trips per-capita axis and crosses the cost axis. Depending on the coefficients for B_0 and B_1, the curve can have different shapes and positions. Because it crosses the cost axis, there is a finite price associated with zero trips per-capita. This is a nice property of the semi-log independent curve which is not shared by the two other log transform functional forms. The Z_{ik} terms are customarily not transformed, the same as in the linear or quadratic model.

Semi-log (Dependent)

This functional form and the double-log form are usually the ones most suited for travel cost analysis. The advantage of these functional forms is that they involve a logarithmic transformation of trips per-capita variable. Research has shown that the trips per-capita variable, in its untransformed state, is heteroskedastic (Strong 1983). Heteroskedasticity refers to the fact that the variance of the residuals varies across the range of the data. The nature of the heteroskedasticity is such that the larger the value of trip per-capita, the more error variance there is. Transforming the trips per-capita variable appears to often alleviate this problem. Users interested in technical treatment heteroskedasticity are referred to any econometrics text (e.g., Kmenta 1971, Maddala 1977). Furthermore, when formal tests for functional form have been performed, the semi-log (dependent) or double-log functional form appears to be superior to either linear, quadratic, or semi-log (independent). The choice of the proper functional form is a subject of some discussion. Users are urged to try different forms and see what happens to the results.

The semi-log dependent functional form is asymptotic to the price axis (fig. 5). Because of this, there is no finite price that predicts zero visitation from an origin to the study site. If B_1 is less than zero, the area under the semi-log dependent curve is finite. To graph the second stage demand curve and calculate consumer surplus in RMTCM, a finite upper bound on cost needs to be selected. For each origin, demand is assumed to fall to zero when the model predicts less than one trip will go from an origin to the site. In this functional form, the Z_{ik} terms are customarily not transformed. That is, simply entering the price of imperfect substitute sites, per-capita income, and other measures of the characteristics of the origin should perform reasonably well.

Double-Log

The double-log functional form is doubly asymptotic (fig. 5). It does not intersect either the price axis or the trips per-capita axis. For consumer surplus calculations, the demand curve is cutoff at the point it predicts one trip will go from the origin to the study site (same as the semi-log dependent). If B_1 is less than -1, the area under the double-log demand curve is finite. In the double-log demand curve, it is customary for the Z_{ik} terms also to be expressed using a logarithmic transformation. In other words, the logarithm of the price of the imperfect substitute site(s), the logarithm of per-capita income, etc., normally are entered as predictors into this demand equation.

Regression Analysis in RMTCM

The five functional forms are meant to give the user flexibility when using RMTCM. The five functional forms allow fitting of quite general models. The B_jZ_{ik} terms let the program account for many substitute sites and other demographic factors. The choice of the proper functional form is complicated. A few suggestions will be given in the section on advanced issues.

When the user first enters the "RUN REGRESSIONS" portion of RMTCM, the prompt

```
DISPLAY LIST OF VARIABLE NAMES  (Y OR N)
?
```

is displayed. Listing the variable names is useful, because it shows the variable names that can be used in the regression. The next prompt to appear is

```
USE ALL VARIABLES IN THE REGRESSION?
(Y OR N)
?
```

A "Y" response results in all variables being used in the regression. The usual response is "N", because population must be in the data set; but it is not normally used in the regression. After a "N" response the prompt

```
USE "VARIABLE NAME"? (Y OR N)
?
```

is displayed. This prompt will be repeated for all of the variables in a data set. If a variable is going to be used in the regression, answer "Y"; otherwise simply press carriage return. Figure 6 gives a worksheet that might help to organize the regressions. After the end of the prompts, RMTCM will ask for the name of the dependent variable by displaying

```
ENTER NAME OF DEPENDENT VARIABLE
?
```

at the terminal. Enter the name of the dependent variable. Do not worry if you indicated the dependent variable will be used in the regression on the previous step; the program works either way.

At this point, the RMTCM program produces a brief regression statistics output. The brief output consists of regression coefficients, t-statistics, probabilities, and R^2. A satisfactory TCM should have negative regression coefficients on the variable representing the cost of visiting a recreation site (note that in the quadratic model one would expect the mixed signs previously described). The R^2s in TCMs are usually not very high, and often range from between 0.1 and 0.5. The R^2 from the semi-log (log-dependent) and double-log function form is not comparable to the R^2 from the other three functional forms (see Comparing R^2 Across Functional Forms). Much literature has been written on how to select the best regression model (Draper and Smith 1966, Kmenta 1971). The R^2, t-statistics, and theoretical reasonableness are all factors that go into selecting the final model. After the brief output the prompt

```
PRODUCE EXPANDED OUTPUT? (Y OR N)
?
```

asks if there should be a diagnostic output of the regression. If "Y" is entered, an analysis of variance summary table will be printed and the residuals will be plotted. Specifically, the residuals are plotted versus the predicted value of the dependent variable. Readers not familiar with how to interpret residual plots are referred to any statistics text which discusses their interpretation (Draper and Smith 1966).

Independent Variable	REGRESSION 1 (Linear) VCAP	REGRESSION 2 (Semi-log(dependent)) LN(VCAP)	REGRESSION 3 (Double-log) LN(VCAP)
IV1	COST	COST	LNCOST
IV2	SUBCOST	SUBCOST	LNSUBCOST
IV3	PCI	PCI	LNPCI
IV4			
IV5			
IV6			
IV7			
Dependent Variable	vcap	ln(vcap)	ln(vcap)

Figure 6.—Worksheet for regression portion of RMTCM.

REPORT WRITING

The next prompt

```
PRODUCE SUMMARY REPORT? (Y OR N)
?
```

asks if a summary report should be generated. The summary report is based on the most recent regression estimated. If the most recent regression is not satisfactory, answer "N" to this prompt and re-estimate a different regression. Integrating the summary report with the regressions is the strength of RMTCM. It frees the user from the unique computations associated with the TCM.

If a "Y" response is given to the report prompt, the message

```
1) LINEAR
2) QUADRATIC
3) SEMI-LOG INDEPENDENT
4) SEMI-LOG DEPENDENT
5) DOUBLE LOG
ENTER FUNCTIONAL FORM USED
?
```

will appear at the terminal. To generate the report, RMTCM must know which functional form was used in the most recent regression. At this point, enter the appropriate number. Then the prompt

```
ENTER VARIABLE NAME FOR ROUND-TRIP COST
?
```

asks for the name of the variable representing the cost of a trip to the study site. In response to this question, enter the variable name, or column number, associated with the cost of traveling from an origin to the recreation site. If a quadratic form was used, there will be a second prompt asking for the name of the cost squared variable. If a double-log functional form was used, the user will first be asked for the names of the variables representing the logarithm of cost and cost itself. Next the prompt

```
ENTER VARIABLE NAME FOR POPULATION
?
```

appears. In response to this question, indicate the name of the variable containing the population of each origin.

After answering the population question, RMTCM responds with the following message.

```
A FEE INCREASE OF (XXXX.XXX) RESULTS IN
ZERO VISITS FROM ALL ORIGINS
THE LAST ORIGIN TO PRODUCE VISITS IS X
ENTER NEW DEMAND CUTOFF POINTS ? (Y OR N)
```

The first line shows how much of an increase in per-person per-trip cost is needed to drive visitation from all the origins to the study site to zero. For example, let

$$VC_i = f(C_i, S_i, Z_i) \qquad [3]$$

represent the functional form the user has fit with multiple regression. Then, the predicted visitation at a given fee increase, ΔC_i, is

$$VC_i(\Delta C_i) = f(C_i + \Delta C_i, S_i, Z_i). \qquad [4]$$

The fee increase needed to drive trips to zero for a given origin i is

$$0 = f(C_i + \Delta C_i^*, S_i, Z_i) \qquad [5]$$

The maximum ΔC_i^* is reported as the largest fee increase required to drive trips to zero from all origins. The case number associated with the maximum is also reported.

No Perfect Substitutes

The prompt asks whether or not new demand cutoff points should be entered. New demand cutoff points should be entered only if a perfect substitute site to the study site has been identified. Recall, a perfect substitute site is one which offers the same recreation opportunities at an equal or higher quality, and has sufficient capacity to handle the increased use that would result if the study site were closed. The price of a perfect substitute should not be used in the demand equation itself. For now, assume there is no perfect substitute site.

After answering "N" to the cutoff prompt, RMTCM will generate a summary report. The first part of the summary report is a table showing various simulated fee increases at the site and how many trips would occur at the site if that fee were charged. A fee increase of zero reflects the existing condition. The predicted number of trips at the zero fee increase should be reasonably close to the actual number of trips now occurring at the site. As a rough guide, plus or minus 25% is reasonably close. If the predicted number of visits is way off, consider trying a different functional form and/or different independent variables. The subsequent fee increases show how simulated visitation falls as fees are increased. The RMTCM program automatically calculates the upper bound of the fee increase and scales the increases between zero and the upper bound. At the upper bound of the predicted fee increases, the table should show zero, or very close to zero, trips.

Continuing under the assumption of no perfect substitute site(s), the next part of the report is a graph of the fee increase/visits table. In the travel cost literature, this is known as a "second stage" demand curve. Underneath the graph is an estimate of the total consumer surplus at the recreation site and the consumer surplus per trip. The total consumer surplus is the area under the second stage demand curve, and represents the net economic benefit to the consumer of the recreation site. This is an estimate of the willingness of recreationists to pay for access to that recreation site over and above their existing expenses. The consumer surplus per trip is the total consumer surplus value divided by the predicted number of trips at a zero fee increase. It can be interpreted as the average willingness-to-pay for a trip.

The total consumer surplus measure given by RMTCM does not reflect the costs of supplying the recreation facility to the public. The net benefits of the recreation site to society is consumer surplus minus the costs of providing the site. Any fees collected by the provider should be calculated as a benefit when calculating net benefit to society.

Following the output of the consumer surplus estimates, a table of revenue and revenue changes is printed. This table indicates how much revenue would be collected by the managing agency if various fees were charged at the recreation site.

The predictions of visitation at various fee increases are generated under the assumption that fees would be increased at the study site and held constant everywhere else. For example, if the study site has four substitute sites, RMTCM assumes that the prices of trips to the substitute sites would remain constant when fees are raised at the study site. This is unlikely if there is an agency-wide or region-wide decision to raise entrance fees. The TCM model cannot predict what would happen to visitation in the face of a system-wide increase in fees.

With Perfect Substitutes

A perfect substitute site sets an upper bound on the willingness of recreationists to pay for entry to the study site. The price of a trip from an origin to the closest perfect substitute site is termed the "demand cutoff" point for that origin. If fees at the study site are raised to a level that the travel cost plus fees exceed the demand cutoff point for an origin, then trips from the origin to the study site are assumed to be zero. This is the logic that is implemented when the demand cutoff option of RMTCM is invoked.

From eq. [5] let

$$C_i^* = C_i + \Delta C_i^*. \qquad [6]$$

C_i^* is the cost at which the demand equation predicts zero trips from origin i. Let the cost of a trip from origin i to the nearest perfect substitute site be represented as C_i'. The C_i' values must be entered by the user, as discussed later in this guide.

When demand cutoff points are used for report writing trips from origin i are modeled as falling to zero whenever

$$\Delta C_i + C_i > \tilde{C}_i \qquad [7]$$

where: $\tilde{C}_i$ = minimum of C_i^* and C_i'.

Regardless of what the demand equation predicts, trips will be assumed to fall to zero if $\Delta C_i + C_i$ is greater than C_i'. Because of this logic, if C_i' is always greater than C_i^*, the cutoff points will have no effect on the report. The logic behind these cutoff points is discussed by Knetsch (1977).

If there is a perfect substitute site, a "Y" response should be given to this

```
ENTER NEW DEMAND CUTOFF POINTS? (Y OR N)
?
```

prompt. Then the prompt

```
1) ENTER NEW DEMAND CUTOFF POINTS ONE
   BY ONE
2) SPECIFY COLUMN OF CUTOFF POINTS
MAKE SELECTION?
```

will ask how those demand cutoff points should be read.

The simplest way to enter demand cutoff points is to specify a column of these values. After indicating a "2" to the demand cutoff menu, RMTCM will prompt the user with

```
ENTER VARIABLE NAME FOR DEMAND CUTOFF
?
```

to determine the name of the variable to use as demand cutoff points. The demand cutoff point for an origin is the cost of a round-trip from that origin to the nearest identified perfect substitute site. If there is more than one perfect substitute, use the one with minimum cost for each origin. After the variable is named, a report will be generated. The demand curve is likely to have the truncated shape shown in figure 7 because of the cutoff points.

If option 1 is selected, RMTCM will display, origin by origin, the price that drives trips to zero, i.e., C_i^*. Following each display, RMTCM will ask for a demand cutoff point. The user should then enter the value of C_i' for each origin. After entering the cutoff points, RMTCM will display

```
ENTER NEW DEMAND CUTOFF POINTS? (Y OR N)
```

again. Answer "N", unless an input error was made, and then RMTCM will produce a summary report taking into account the demand cutoff points.

The perfect substitution assumption is a strong one. If an analyst is not certain about whether a site is a perfect substitute, RMTCM can be run both ways. To run RMTCM with a site as an imperfect substitute, the imperfect substitute price term should be included in the regression equation. With the questionable site entered as an imperfect substitute, the second stage demand curve can be generated without demand cutoff points. The second analysis then would run RMTCM under the assumption that the site was a perfect substitute. In this case, the price of the perfect substitute site would not be entered in the regression equation. Instead, the perfect substitute price would be reflected as column of demand cutoff points. The reason the perfect substitute price cannot be entered into the regression equation is that if a site is a perfect substitute, it is assumed to be the same commodity as the study site. Economic theory does not allow the price of the single commodity to be entered into a demand curve twice.

EXITING RMTCM

To exit the program, select option #5 when the main menu is displayed, and the prompt

```
WANT TO SAVE DATA AS RMTCM SYSTEM FILE
(Y OR N)
?
```

will be displayed. To save the data and associated variable names answer "Y", and the prompt

```
ENTER NAME OF RMTCM SYSTEM FILE
?
```

asks for a valid file name. Enter the name of the file and a carriage return, then the file will be saved and the program will be finished. If means were substituted for missing data on the initial data input step, the substituted mean values will be saved on the RMTCM system file.

Regardless of whether a RMTCM system file was saved a file containing an exact duplicate of what occurred during the RMTCM session will have been automatically saved. On the FCCC Univac version, this file is named "RM*TCM-LOG.". (see section "Accessing RMTCM on the USDA Computer"); on the personal computer version, the file is named "RMTCM.LOG". This file can be printed for a permanent copy of the RMTCM run.

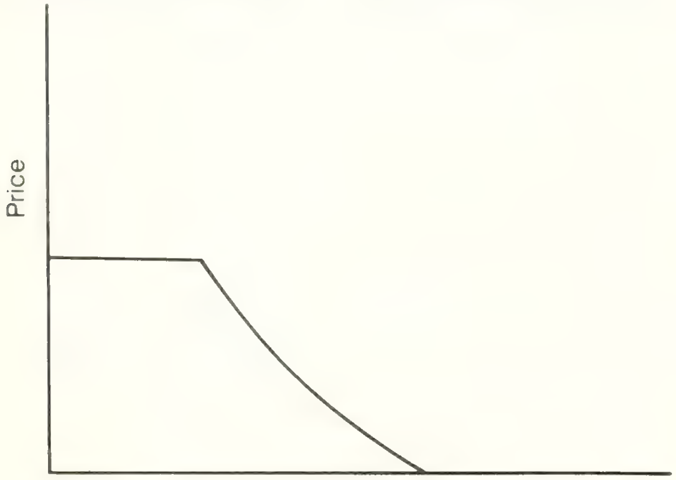

Figure 7.—Truncated second stage demand curve.

ADVANCED ISSUES

Users of RMTCM might want to use the program to do things it was not originally intended for. Also, technical issues will arise. What follows is an attempt to address some of these issues. Readers of this section are assumed to be fairly familiar with the TCM and statistical data analysis.

FINER FEE INCREMENTS

The RMTCM summary report usually generates tables of trips associated with rather large fee increases. For the purpose of formulating policies related to pricing a recreation area, it might be useful to have more resolution at the lower end of the fee/visits schedule. This resolution can be obtained by imposing a set of artificial demand cutoff points. Generate a new column of data in the modify data option of RMTCM. The new column of data will be the existing cost of travel from an origin to the study site plus a constant. The amount of the constant will set the upper bound of the fee increase table. Fit the model and then answer yes to the demand cutoff question. Specify this new column of data as a column of cutoff points, and the desired results will be obtained. If the constant added was 10, the fee/visits schedule will reflect 20 even increments between $0 and $10. Keep in mind that the consumer surplus calculations will be meaningless. However, the fee/visit schedule will be accurate between $0 and $10.

CALCULATING DISTANCES

In a travel cost model with many origins and many recreation sites calculating the distances from each origin to each site can be quite tedious. The usual means to calculating distances is a road map. An alternative technique in the case of many origins and many sites is to use geometry to estimate calculate distances. For any two points A and B, the airline distances between them is (U.S. Department of Commerce 1978):

$$A = [\cos^{-1}((\sin a \sin b) + (\cos a \cos b \cos P))]k_1 \quad [8]$$

where A = airline distance between A and B
a = latitude of point A
b = latitude of point B
P = degrees of longitude between A and B, and
k_1 = distance, in miles, of one degree at a given latitude (69.055 is a general case).

It is assumed that latitude and longitude are measured in degrees and tenths of degrees, not in degrees followed by hours, minutes, and seconds. Another way to measure distance with geometry is to determine the checkerboard, or right angle, distance between any two points. The checkerboard distance between any two points A and B is defined as

$$CB = k_1L + k_2P \qquad [9]$$

where CB = checkerboard distance between two points A and B
L = degrees of latitude between points A and B, and
k_2 = miles in one degree of longitude (54 is a general case).

By recording the latitude and longitude of the recreation sites and origins, the checkerboard and airline distances between any two points can be calculated easily. Once the airline and/or checkerboard distances are calculated, the problem is to convert them into driving distances. To do this take a random sample of the distances that need to be calculated from a road map. A correction factor can than be found and used to predict driving distances. The predicted driving distance between two points A and B then would be

$$D\hat{D} = k_4G \qquad [10]$$

where $D\hat{D}$ = predicted driving distance between A and B
$k_4 = \dfrac{k_5}{k_6}$
k_5 = average driving distance for sample of points
k_6 = average distance for sample of points based on geometry, and
G = distance between a and b based on geometry.

Whether or not to use the airline distance or checkerboard distance or geometrically based distances is a matter of choice. The best predictor of driving distances is the one to select.

A more formal way of relating driving distances to geometrically based distances is to use regression analysis. Rosenthal (1985) used regression analysis to estimate the following equation relating driving distances to geometrically based distances.

$$D\hat{D} = 6.86 + 1.075A + 0.4789(CB - A) \qquad [11]$$
$$R^2 = 0.98.$$

The U.S. Department of Commerce discusses this problem in more detail and has a published set of road circuity factors (U.S. Department of Commerce 1978).

ORIGINS WITH NO VISITS

Frequently, no trips to the recreation sites will have been sampled from some origins in the market area. For example, if origins are defined as counties within a 100-mile radius of the recreation site, trips from some counties might not have been sampled. The analyst is faced with the question of what to do with counties from which no visitation was observed. The solution depends on the functional form being used.

If the linear, quadratic, or semi-log independent functional forms are used, then these zeros should be retained in the travel cost model. Zero trips from an origin to the site is a valid observation, which should be entered as a case, just like any other origin. In the example data set shown in table 1 if no trips had been observed from origin 10, then a zero would be entered in the trips column for that origin. The regression analysis, distance to cost conversions, and any other modifications would proceed as normal.

If the semi-log dependent or double-log functional forms are used, retaining zeros is not feasible. Taking the logarithm of zero is an undefined mathematical operation. A simple way to eliminate the zeros is to redefine the origins so that there are no origins with zero visitation. If origin 10 in figure 1 had a zero, the logical alternative would be to combine it with origin 9, 6, or 11. If origin 10 is combined with origin 9, then an aggregate origin representing the 9,10 combination would result. This would reduce the number of cases in the data set from 12 to 11. The visitation from this new origin would be the trips from 9 plus the trips from 10. In the example data set, there would be 356 trips from the new aggregate origin (assume there are 356 trips from origin 9 and zero trips from origin 10). The population of the new origin would be the sum of the two populations, or 43,000. To calculate distances, per-capita income, and other demographic statistics population weighted averages must be used. The population weighted per-capita income and distance to the study site for the new aggregate origin would be $7651 and 65 miles, respectively. The travel cost model then can be run using 11 cases with positive visitation recorded from all origins.

MULTICOLLINEARITY

Multicollinearity refers to the condition of two or more predictor variables in the demand equation being highly correlated.

Consider the layout of origins and recreation sites shown in figure 8. To run the TCM, four distances for each origin must be calculated — the distance from the origin to the study site and to each of the three substitute sites. When these data are subsequently used in the regression portion of RMTCM, multicollinearity between the sites can cause a problem. The two substitute sites located in origin 5 are almost right next to each other. Therefore, the distances to each of them from each origin are almost identical. In such a case, it is not necessary to calculate the distance to both sites. One of the sites, or a location between the sites, can be chosen to represent the combination of those two sites. Combining substitute sites in this manner only should be done when they are very close to each other. Otherwise, it is best to enter the separate sites in the RMTCM model.

A much more severe problem occurs if the substitute site is very close to the study site. For example, assume a substitute site is located at point "A" in origin 7. To run the TCM, the distance from each origin to each site in the market area is needed. Because the study site and point A are so close together, the distance measured to these sites from each origin will be almost identical. When the regression is run, little confidence can be placed on the own-price regression coefficient for the study site.

There are three ways to deal with this problem. First, the study site can be redefined to represent the combination of the original study site plus A. In this case, the TCM will value the two sites as a single site. Total trips would be defined as trips to either the study site or site A. Some central point between the study site and site A would be used for calculating distances. When the site is redefined in this manner, it is not possible to use the TCM to make statements about the value of either the original study site or site A in isolation.

The second way to deal with the problem shown in figure 8 is to assume that the site represented by A is a perfect substitute to the study site. Recall that a perfect substitute must provide recreation opportunities of equal or higher opportunities and have enough excess capacity to maintain this quality in the face of the increased use that would occur if the study site were closed. Then, the price of site A would not be used in the regression equation. Instead, the prices of trips to site A would be used for demand cutoff points. If site A is assumed to be a perfect substitute to the study site, the demand curve will be truncated at a very low level. The economic benefit of the study site under such an assumption would be very low. This makes sense, because if there is a perfect substitute site located right next to the study site, the loss in recreational opportunities by removing the study site is not very great.

The final way to deal with the multicollinearity problem is simply not to use the TCM. The TCM is not well suited to estimating the value of the study site alone in the face of such high multicollinearity. A study using the contingent valuation method may be better suited to determining the value of the study site.

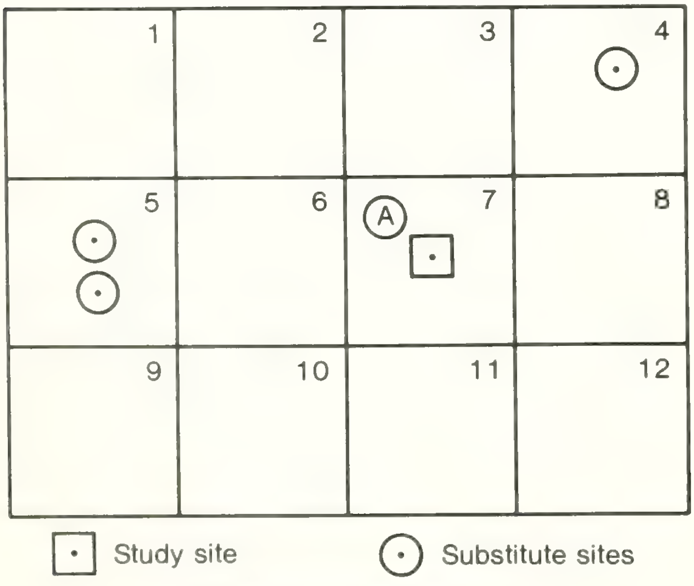

Figure 8.—Multicollinearity.

COMPARING R^2 ACROSS FUNCTIONAL FORMS

Many statistical texts discuss the issue of how to select the "best" regression. Important factors to consider are theoretical reasonableness of the model, how well the model fits the data, residual plots, and the statistical significance of individual regression coefficients. The reader is referred to any good statistics text for a discussion of these issues.

With RMTCM, the user has the option of fitting functional forms where the logarithm of trips per-capita is used as the dependent variable. The R^2 from these regressions cannot be meaningfully compared to the R^2 of regressions using trips per-capita as the dependent variable. This occurs because the dependent variables are measured in different units.

To compare a log dependent variable regression with a regular regression, the dependent variables must be transformed into equivalent units. Following Rao and Miller (1965) redefine the dependent variable as

$$VC_i^* = VC_i/g \qquad [12]$$

where $g = \exp[(1/n) \sum_{i=1}^{n} (\ln VC_i)]$

is the geometric mean of trips per capita. After this standardization fit, for example,

$$VC_i^* = B_0 + B_1 C_1 + \epsilon_i \qquad [13]$$

and

$$LN(VC_i^*) = \alpha_0 + \alpha_1 Ln(C_i) + \epsilon_i'. \qquad [14]$$

The equation with the lower residual sum of squares is the better fit. Standardizing by dividing by the geometric mean of the dependent variable allows direct comparison of residual sums of squares.

INDIVIDUAL OBSERVATION TRAVEL COST MODELS

The RMTCM program can be tricked into running individual observation based TCMs (Brown and Nawas 1973). In the zonal TCM, visits per-capita from each origin is regressed on price, income, and other predictors. In the individual TCM, the number of times each person visits the site is regressed on price, income, and other variables. The difference between the two approaches results from aggregation.

The individual observation based TCM can be run on RMTCM by treating each individual as a zone with a population of one. An individual observation based TCM run on RMTCM will have as many origins as there are individual observations. A column of 1s should be used to represent the population of these pseudo-origins. Once this is done, the analysis proceeds in exactly the same manner as the zonal TCM.

Brown et al. (1983) pointed out a serious shortcoming in the individual observation based TCM. Because only participants are included in the data set, the individual based model does not reflect the fact that a person might stop visiting the site altogether when faced with a price increase. To correct this deficiency they suggest using a new dependent variable termed "individual observed visits per-capita."

The details of their approach cannot be described here except to say that such a model can be run easily on RMTCM. This model is clearly superior to the simple individual observation based TCM. To use this approach, first calculate individual observed visits per-capita as

$$\mathrm{vcap}^{*}_{ir} = t_{ir}\,(R_i/P_i)S \qquad [15]$$

where vcap^{*}_{ir} = individual observed visits per-capita for the rth sampled recreationist ($r = 1, R_i$) from the ith ($i = 1,n$) origin

t_{ir} = number of trips to the study site made by the rth person from the ith zone

R_i = number of recreationists sampled from the ith zone

P_i = population of the ith zone, and

S = expansion factor to correct for the sampling rate, i.e., 1/(proportion of visitors sampled).

Then use vcap^{*}_{ir} as the dependent variable in RMTCM; $\ln(\mathrm{vcap}^{*}_{ir})$ also can be used as a dependent variable when fitting logarithmic functional forms.

Every value of vcap^{*}_{ir} will be treated as a zone in RMTCM. Because of the way RMTCM calculates benefits, a population is needed for each one of these zones. When using RMTCM to run the Brown et al. (1983) model, the population associated with a given value of vcap^{*}_{ir} is (P_i/R_i). Every observation from the ith origin has the same population, (P_i/R_i).

Do not get confused between the zones formed by the user and the number of zones RMTCM thinks there are. In the user's mind there are n zones ($i = 1,n$). When fooling RMTCM into emulating the Brown et al. (1983) model, the program thinks there are $(R_1 + R_2 + \ldots R_n)$ zones. There are as many zones as there are people. Each of these people-zones has an associated population, (P_i/R_i).

Once the value of vcap^{*}_{ir} and the associated population has been entered the analysis proceeds as normal. Users can try the sample data given in table 1 of Brown et al. (1983) as a check to see if they have set up the problem correctly.

The Brown et al. model assumes that the data on individual visit rates to a specific site were collected by either a household survey or by a survey of license holders for a particular activity (e.g., fishing). Persons with zero values for t_{ir} are not included in the analysis. With such a sampling scheme, all persons visiting the site one or more times have an equal probability of being sampled. In contrast, if persons are interviewed as they enter or exit the site, this equal probability property does not hold. Persons who visit the site often are more likely to be sampled than are infrequent visitors. The reasonableness of using the Brown et al. (1983) approach with data collected at the recreation site is an open question. Estimating regression models when there is sample stratification on the dependent variable is discussed by Hausman and Wise (1981).

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APPENDIX

Example of RMTCM Output

The data shown in table 1 were used to generate this example of RMTCM output. Comments shown were included by the authors to help readers understand the example. RMTCM does not generate these comments. This example was run on a personal computer (PC). Output from the RMTCM UNIVAC version at FCCC is the same except for possible differences in computational accuracy between the two computers. Also, differences in system-oriented file names are noted in the comments at the end of the example run.

```
WELCOME TO RMTCM.
RMTCM WAS DEVELOPED BY D. ROSENTHAL, D. DONNELLY, M. SCHIFFHAUER , AND G. BRINK AT
THE ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION, FORT COLLINS, COLORADO. THIS
PROGRAM IS IN THE PUBLIC DOMAIN AND, THEREFORE, MAY NOT BE COPYRIGHTED. IT MAY BE
DUPLICATED AND/OR DISTRIBUTED PROVIDED THAT NO FEE IS CHARGED AND THIS MESSAGE IS
NOT REMOVED. A USER'S GUIDE IS AVAILABLE FROM RMS PUBLICATIONS, 240 W. PROSPECT ROAD,
FORT COLLINS, CO 80526.

                                                         (BRACKETED COMMENTS ADDED
                                                         TO HELP INTERPRET OUTPUT)
 ENTER OPTION (0 FOR MENU)
?
            0                                            (OPENING MESSAGE)
1) INPUT DATA
2) DISTANCE TO COST CONVERSION
3) MODIFY DATA
4) RUN REGRESSIONS AND REPORTS                           (MAIN MENU)
5) EXIT RMTCM PROGRAM
 ENTER OPTION (0 FOR MENU)
?
            1
1) INPUT DATA INTERACTIVELY FROM KEYBOARD
2) READ AN EXTERNAL ASCII DATA FILE
3) READ A PREVIOUSLY CREATED RMTCM SYSTEM FILE
4) RETURN TO MAIN MENU
CHOOSE FORM OF DATA ENTRY (1,2,3, OR 4)
?
      2
 ENTER ASCII DATA FILE NAME
?                                                        (INPUT DATA: FILE NAME IS
                                                         TABLE1)
  table1
  OPENING table1
 ENTER NUMBER OF VARIABLES
?
            6
MAXIMUM NNUMBER OF CASES IS 666
NAME VARIABLES (0-8 CHARACTERS)
C1
 ENTER NAME
?
  POP                                                    (NAMING VARIABLES)
C2
 ENTER NAME
?
  VISITS
C3
 ENTER NAME
?
  PCI
C4
```

```
  ENTER NAME
?
   DIS
C5
  ENTER NAME
?
   SUBDIS
C6
  ENTER NAME
?
   PERDIS
  SPECIFY INPUT FORMAT
                                           ?  (Y OR N)
?
   N                                                          (FREEFIELD FORMAT)

  NUMBER OF CASES READ = 12

FIRST FOUR LINES OF DATA ARE AS FOLLOWS. . .

    .3000E+05       224.0       8000.       67.00       30.00       136.0
    9000.           69.00       7000.       42.00       1.000       106.0
    6000.           77.00       8100.       30.00       30.00       76.00
    9000.           110.0       7900.       42.00       60.00       47.00

LAST LINE OF DATA IS AS FOLLOWS. . .

    .1400E+05       195.0       7375.       42.00       85.00       64.00

  LIST ALL THE DATA
                                           ?  (Y OR N)
?
   Y
    .3000E+05       224.0       8000.       67.00       30.00       136.0
    9000.           69.00       7000.       42.00       1.000       106.0
    6000.           77.00       8100.       30.00       30.00       76.00
    9000.           110.0       7900.       42.00       60.00       47.00
    .3000E+05       282.0       8800.       60.00       42.00       136.0
    .1200E+05       141.0       7300.       30.00       30.00       106.0
    4000.           87.00       9100.       1.000       42.00       76.00
    .1200E+05       202.0       8150.       30.00       67.00       47.00
    .4000E+05       356.0       7700.       67.00       67.00       142.0
    3000.           35.00       7000.       42.00       60.00       114.0
    6000.           93.00       8100.       30.00       67.00       87.00
    .1400E+05       195.0       7375.       42.00       85.00       64.00

  SUBSTITUTE MEANS FOR MISSING VALUES      ?  (Y OR N)
?
   N

  ENTER OPTION (0 FOR MENU)                                   (DISTANCE TO COST)
?
                2
  ENTER AVERAGE TRAVEL SPEED (MPH)
?
         50.00000
  ENTER COST/MILE FOR VEHICLE ($)
?
         .12000
  ENTER PERSONS/VEHICLE
?
```

```
        2.50000
  ENTER ONE-WAY (O) OR ROUND-TRIP (R)
?
   O
  ENTER COST OF TIME ($ PER HOUR)
?
        1.89000
  ENTER PER VEHICLE ENTRY FEE AT THE SITE ($)
?
        .00000
  ENTER NAME OF VARIABLE TO CONVERT
?
   DIS
  ENTER NAME OF NEW VARIABLE (C7)
?
   COST
FIRST 4 CASES ARE AS FOLLOWS. . .                          (LIST CONVERTED VALUES)

                C4          C7
   CASE         DIS             COST
      1       67.000      11.497
      2       42.000       7.207
      3       30.000       5.148
      4       42.000       7.207

  LIST ALL THE COST VALUES              ?  (Y OR N)
?
   Y

                C4          C7
   CASE         DIS             COST
      1       67.000      11.497
      2       42.000       7.207
      3       30.000       5.148
      4       42.000       7.207
      5       60.000      10.296
      6       30.000       5.148
      7        1.000        .172
      8       30.000       5.148
      9       67.000      11.497
     10       42.000       7.207
     11       30.000       5.148
     12       42.000       7.207
  ANOTHER, WITH SAME VALUES             ?  (Y OR N)
?
   Y                                                       (CONVERT NEW VARIABLES
  ENTER NAME OF VARIABLE TO CONVERT                        WITH SAME INPUT PARAMETERS)
   C5
  ENTER NAME OF NEW VARIABLE (C8)
?
   SUBCOST

FIRST 4 CASES ARE AS FOLLOWS. . .

                C5            C8
   CASE       SUBDIS        SUBCOST

      1       30.000       5.148
      2        1.000        .172
      3       30.000       5.148
      4       60.000      10.296
  LIST ALL THE COST VALUES                 ?  (Y OR N)
                                                          (CARRIAGE RETURN DEFAULTS
                                                          TO N FOR ALL "Y OR N"
                                                          PROMPTS)
  ANOTHER, WITH SAME VALUES                ?  (Y OR N)
?
   Y
  ENTER NAME OF VARIABLE TO CONVERT
?
   PERDIS
  ENTER NAME OF NEW VARIABLE (C9)
?
   PERCOST

 FIRST 4 CASES ARE AS FOLLOWS. . .

                C6             C9
   CASE       PERDIS         PERCOST

       1      136.000       23.338
       2      106.000       18.190
       3       76.000       13.042
       4       47.000        8.065

  LIST ALL THE COST VALUES                 ?  (Y OR N)
?
   N

  ANOTHER, WITH SAME VALUES                ?  (Y OR N)
?
   N
  ENTER OPTION (0 FOR MENU)
?
           0

 1)  INPUT DATA
 2)  DISTANCE TO COST CONVERSION
 3)  MODIFY DATA
 4)  RUN REGRESSIONS AND REPORTS
 5)  EXIT RMTCM PROGRAM
  ENTER OPTION (0 FOR MENU)
?
           3                                              (MODIFY DATA)

 0)  RELIST MENU
 1)  ADD 2 COLUMNS (SEE ALSO OPTION 9)
 2)  SUBTRACT (FIRST-SECOND)
 3)  MULTIPLY (FIRST*SECOND)
 4)  DIVIDE (FIRST/SECOND)
 5)  MULTIPLY (COLUMN*CONSTANT)
 6)  POWER (COLUMN**CONSTANT)
 7)  NATURAL LOGARITHM
 8)  ENTER NEW COLUMN OF DATA
 9)  ADD A CONSTANT TO A COLUMN
10)  EXIT TO MAIN MENU

  ENTER MODIFY CHOICE (0 FOR MODIFY MENU)
?
           4                                              (DIVIDE FIRST COLUMN
  ENTER NAME OF FIRST INPUT COLUMN                        BY SECOND)
?
```

```
   VISITS
  ENTER NAME OF SECOND INPUT COLUMN
?                                                            (COLUMN NUMBER CAN BE
   C1                                                        USED IN PLACE OF VARIABLE
                                                             NAME)
  PUT RESULT IN EXISTING COLUMN          ?  (Y OR N)
?
   N
  ENTER NAME FOR NEW VARIABLE (C10)
?
   VCAP

 FIRST 4 CASES ARE AS FOLLOWS. . .

                    C2           C1           C10
   CASE           VISITS        POP           VCAP

       1           224.00       30000.      .74667E-02
       2           69.000       9000.0      .76667E-02
       3           77.000       6000.0      .12833E-01
       4           110.00       9000.0      .12222E-01
  LIST ALL NEW VALUES                    ?  (Y OR N)
?
   N
  ENTER MODIFY CHOICE (0 FOR MODIFY MENU)
?
              0

0)  RELIST MENU
1)  ADD 2 COLUMNS (SEE ALSO OPTION 9)
2)  SUBTRACT (FIRST-SECOND)
3)  MULTIPLY (FIRST*SECOND)
4)  DIVIDE (FIRST/SECOND)
5)  MULTIPLY (COLUMN*CONSTANT)
6)  POWER (COLUMN**CONSTANT)
7)  NATURAL LOGARITHM
8)  ENTER NEW COLUMN OF DATA
9)  ADD A CONSTANT TO A COLUMN
10) EXIT TO MAIN MENU

  ENTER MODIFY CHOICE (0 FOR MODIFY MENU)
?
              7                                              (COMPUTE NATURAL LOG OF
  ENTER NAME OF INPUT COLUMN                                 VISITS PER CAPITA)
?
   VCAP

  PUT RESULT IN EXISTING COLUMN          ?  (Y OR N)
?
   N
  ENTER NAME FOR NEW VARIABLE (C11)
?
   LVCAP

 FIRST 4 CASES ARE AS FOLLOWS. . .

                   C10           C11
   CASE            VCAP         LVCAP

     1          .74667E-02     -4.8973
     2          .76667E-02     -4.8709
     3          .12833E-01     -4.3557
     4          .12222E-01     -4.4045
 LIST ALL NEW VALUES                   ?  (Y OR N)
?
  N
 ENTER MODIFY CHOICE (0 FOR MODIFY MENU)
?
           10                                          (EXIT MODIFY)
 ENTER OPTION (0 FOR MENU)
?
           4                                           (START REGRESSION)

 DISPLAY LIST OF VARIABLE NAMES        ?  (Y OR N)
?
  Y
CURRENT VARIABLES ARE AS FOLLOWS:
  C1              POP
  C2              VISITS
  C3              PCI
  C4              DIS
  C5              SUBDIS                               (LISTING VARIABLES)
  C6              PERDIS
  C7              COST
  C8              SUBCOST
  C9              PERCOST
  C10             VCAP
  C11             LVCAP

 USE ALL VARIABLES IN THE REGRESSION   ?  (Y OR N)
?                                                      (SELECT VARIABLES FOR
  N                                                    REGRESSION)

  USE POP                              ?  (Y OR N)
?
                                                       (CARRIAGE RETURN
                                                       DEFAULTS TO N)
  USE VISITS                           ?  (Y OR N)
?


  USE PCI                              ?  (Y OR N)
?
  Y

  USE DIS                              ?  (Y OR N)
?


  USE SUBDIS                           ?  (Y OR N)
?


  USE PERDIS                           Y  (Y OR N)
?


  USE COST                             ?  (Y OR N)
?
  Y

  USE SUBCOST                          ?  (Y OR N)
?
  Y
```

```
   USE PERCOST                              ?  (Y OR N)
?


   USE VCAP                                 ?  (Y OR N)
?


   USE LVCAP                                ?  (Y OR N)
?

  ENTER NAME OF DEPENDENT VARIABLE                          (NAME DEPENDENT VARIABLE:
                                                            FUNCTIONAL FORM IS
?                                                           LINEAR)
   VCAP
DEPENDENT VARIABLE IS VCAP

        BRIEF REGRESSION STATISTICS

                                                            (BRIEF OUTPUT)

R SQUARED = .981
COLUMN NAME          COEFFICIENT          T STATS        PROB
   CONSTANT            .329790E-02          1.223        .2561
   C3  PCI             .166746E-05          5.198        .0008
   C7  COST           -.104919E-02         15.981        .0000
   C8  SUBCOST         .398056E-03          7.909        .0000

  PRODUCE EXPANDED OUTPUT                   ?  (Y OR N)
?                                                           (LENGTHY OUTPUT)
   N

  PRODUCE SUMMARY REPORT                    ?  (Y OR N)
?
   N                                                        (NO REPORT, TRY NEW
                                                            FUNCTIONAL FORM)

  ENTER OPTION (0 FOR MENU)
?
          4

  DISPLAY LIST OF VARIABLE NAMES            ?  (Y OR N)
?
   N

  USE ALL VARIABLES IN THE REGRESSION       ?  (Y OR N)
?                                                           (SELECT NEW VARIABLES
   N                                                        FOR REGRESSION)

   USE POP                                  ?  (Y OR N)
?
   USE VISITS                               ?  (Y OR N)
?


   USE PCI                                  ?  (Y OR N)
?
   Y

   USE DIS                                  ?  (Y OR N)
?
```

```
    USE SUBDIS                          ?  (Y OR N)
?


    USE PERDIS                          ?  (Y OR N)
?


    USE COST                            ?  (Y OR N)
?
    Y

    USE SUBCOST                         ?  (Y OR N)
?
    Y

    USE PERCOST                         ?  (Y OR N)
?


    USE VCAP                            ?  (Y OR N)
?


    USE LVCAP                           ?  (Y OR N)
?

  ENTER NAME OF DEPENDENT VARIABLE
?
   LVCAP
DEPENDENT VARIABLE IS LVCAP                                (FUNCTIONAL FORM IS
                                                           SEMI-LOG DEPENDENT)
      BRIEF REGRESSION STATISTICS


                                                           (BRIEF OUTPUT)


R SQUARED = .993
COLUMN                COEFFICIENT        T STATS        PROB

   CONSTANT           -.491111E+01        39.603        .0000
   C3  PCI             .931798E-04         6.316        .0002
   C7  COST           -.821803E-01        27.217        .0000
   C8  SUBCOST         .378289E-01        16.342        .0000

  PRODUCE EXPANDED OUTPUT              ?  (Y OR N)
?
   N

  PRODUCE SUMMARY REPORT               ?  (Y OR N)
?
   Y

1) LINEAR
2) QUADRATIC
3) SEMI-LOG INDEPENDENT
4) SEMI-LOG DEPENDENT
5) DOUBLE LOG
  ENTER FUNCTIONAL FORM USED
?                                                          (SELECT FUNCTIONAL FORM)
             4
  ENTER VARIABLE NAME FOR ROUND-TRIP COST
?
```

```
    COST
  ENTER VARIABLE NAME FOR POPULATION
?
    POP
A FEE INCREASE OF     71.709 RESULTS IN ZERO VISITS FROM ALL ORIGINS
    - THE LAST ORIGIN TO PRODUCE VISITS IS     9

  ENTER NEW DEMAND CUTOFF POINTS       ?  (Y OR N)
?
    N
                                                        (NO CUTOFF POINTS USED)
FEE INCREASE       TOTAL VISITS

           .000            1869.33
          3.774            1370.83
          7.548            1005.27                      (SUMMARY REPORT)
         11.323             737.19
         15.097             540.60
         18.871             396.44
         22.645             290.72
         26.419             213.19
         30.193             156.34
         33.968             114.65
         37.742              84.08
         41.516              61.65
         45.290              44.38
         49.064              32.54
         52.838              21.97
         56.613              14.35
         60.387               8.76
         64.161               5.45
         67.935               2.43
         71.709               1.00
                                SECOND STAGE DEMAND CURVE
COST INCREASE (DOWN) BY TOTAL VISITS (ACROSS)

       .45E+02
       .
       .   1
       .
       .
       .    1                                    (PLOT OF SECOND STAGE
       .                                          DEMAND CURVE)
       .
       .     1
       .      1
.31E+02
       .
       .        1
       .
       .
       .          1
       .
       .             1
       .
       .
.16E+02                   1
       .
       .                        1
       .
       .
       .                                  1
       .
       .                                             1
       .
       .
.00E+001                                                            1
         +.........+.........+.........+.........+.........+.........+

 .32E+02   .35E+03   .67E+03   .98E+03   .13E+04   .16E+04   .19E+04
```

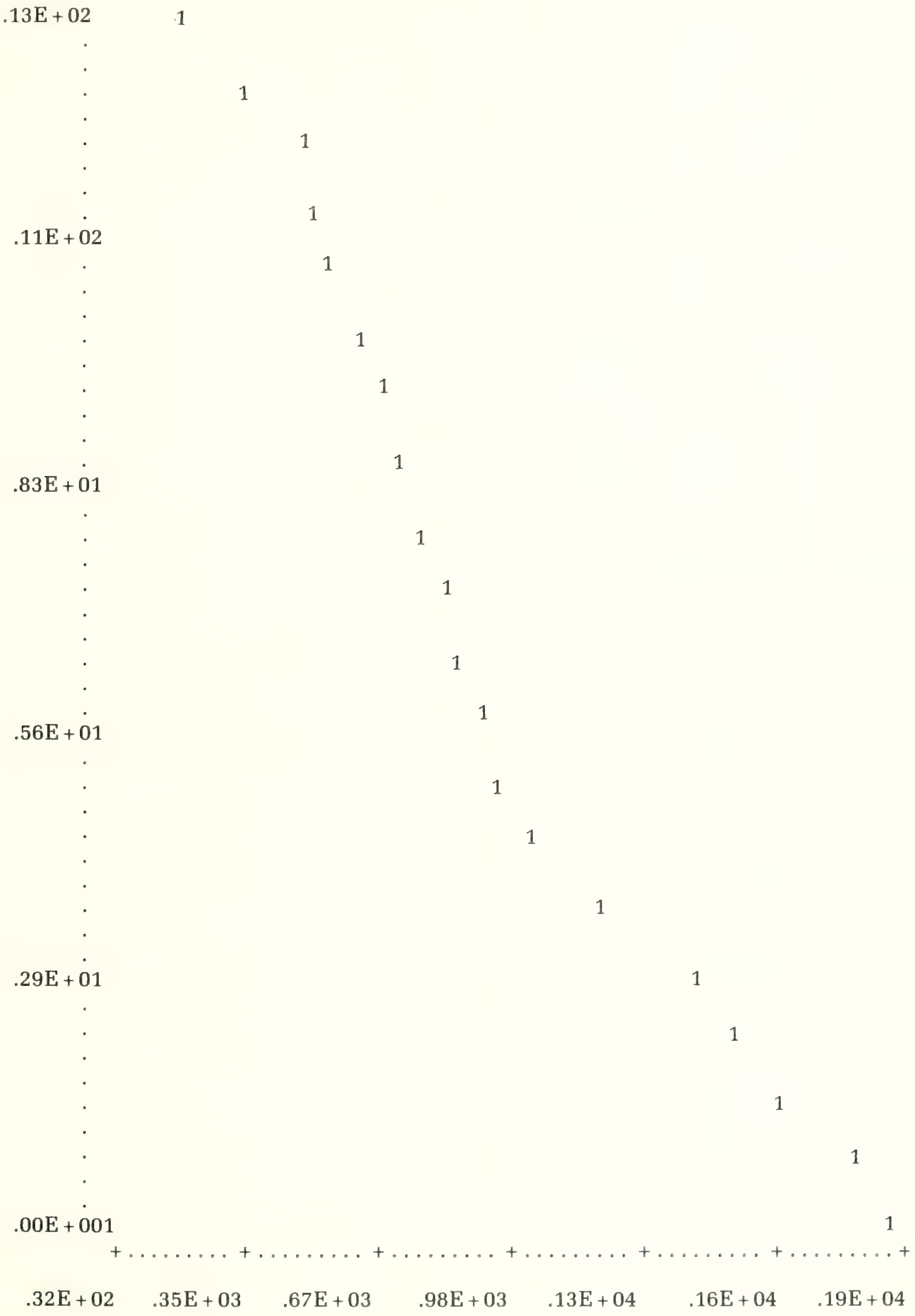
```
CONSUMER SURPLUS = 22780.97                                    (CONSUMER SURPLUS)
C.S./TRIP =             12.19


 ADDITIONAL FEE      REVENUE      CHANGE IN REVENUE
           3.77      5173.76                5173.76
           7.55      7588.13                2414.36            (FEE REVENUE TABLE)
          11.32      8346.87                 758.75
          15.10      8161.32                -185.55
          18.87      7481.16                -680.17
          22.65      6583.37                -897.79
          26.42      5632.39                -950.98
          30.19      4720.44                -911.95
          33.97      3894.34                -826.11
          37.74      3173.14                -721.20
          41.52      2559.65                -613.49
          45.29      2009.77                -549.88
          49.06      1596.63                -413.13
          52.84      1160.83                -435.80
          56.61       812.62                -348.21
          60.39       529.27                -283.35
          64.16       349.50                -179.78
          67.94       164.88                -184.62
          71.71        71.71                 -93.17

                                                               (RE-ESTIMATE SAME MODEL:
  ENTER OPTION (0 FOR MENU)                                    SUMMARY REPORT WILL USE
?                                                              DEMAND CUTOFF POINTS)
               4

  DISPLAY LIST OF VARIABLE NAMES          ?  (Y OR N)
?
   N

  USE ALL VARIABLES IN THE REGRESSION     ?  (Y OR N)
?
   N

   USE POP                                ?  (Y OR N)
?

   USE VISITS                             ?  (Y OR N)
?

   USE PCI                                ?  (Y OR N)
?
   Y

   USE DIS                                ?  (Y OR N)
?
   USE SUBDIS                             ?  (Y OR N)
?


   USE PERDIS                             ?  (Y OR N)
?


   USE COST                               ?  (Y OR N)
?
   Y
```

```
    USE SUBCOST                        ?  (Y OR N)
?
    Y

    USE PERCOST                        ?  (Y OR N)
?


    USE VCAP                           ?  (Y OR N)
?


    USE LVCAP                          ?  (Y OR N)
?

  ENTER NAME OF DEPENDENT VARIABLE
?
    LVCAP
DEPENDENT VARIABLE IS LVCAP

             BRIEF REGRESSION STATISTICS

                                                                (SAME MODEL AS BEFORE)

R SQUARED = .993
COLUMN NAME        COEFFICIENT     T STATS      PROB

    CONSTANT          -.491111E+01       39.603      .0000
    C3  PCI            .931798E-04        6.316      .0002
    C7  COST          -.821803E-01       27.217      .0000
    C8  SUBCOST        .378289E-01       16.342      .0000

  PRODUCE EXPANDED OUTPUT              ?  (Y OR N)
?
    N

  PRODUCE SUMMARY REPORT               ?  (Y OR N)
?   Y

1) LINEAR
2) QUADRATIC
3) SEMI-LOG INDEPENDENT
4) SEMI-LOG DEPENDENT
5) DOUBLE LOG
  ENTER FUNCTIONAL FORM USED
?
               4
  ENTER VARIABLE NAME FOR ROUND-TRIP COST
?
    COST
  ENTER VARIABLE NAME FOR POPULATION
?
    POP
A FEE INCREASE OF     71.709 RESULTS IN ZERO VISITS FROM ALL ORIGINS
    - THE LAST ORIGIN TO PRODUCE VISITS IS      9

  ENTER NEW DEMAND CUTOFF POINTS       ?  (Y OR N)
?
    Y                                                          (ENTER CUTOFF POINTS)
1) ENTER NEW DEMAND CUTOFF POINTS ONE BY ONE
2) SPECIFY COLUMN OF CUTOFF POINTS
```

```
MAKE SELECTION (1 OR 2)
?
      2
  ENTER VARIABLE NAME FOR DEMAND CUTOFF
?
    PERCOST

  LIST NEW CUTOFF POINTS                     ?  (Y OR N)
?
    Y
LISTED BELOW ARE THE PRICES THAT DRIVE TRIPS TO ZERO WITH CUTOFF POINTS
IN EFFECT. SEE USER'S GUIDE.
ORIGIN       1      23.338
ORIGIN       2      18.190
ORIGIN       3      13.042                                    (LISTING CUTOFF POINTS)
ORIGIN       4       8.065
ORIGIN       5      23.338
ORIGIN       6      18.190
ORIGIN       7      13.042
ORIGIN       8       8.065
ORIGIN       9      24.367
ORIGIN      10      19.562
ORIGIN      11      14.929
ORIGIN      12      10.982
A FEE INCREASE OF     13.042 RESULTS IN ZERO VISITS FROM ALL ORIGINS
   - THE LAST ORIGIN TO PRODUCE VISITS IS      9

  ENTER NEW DEMAND CUTOFF POINTS        ?  (Y OR N)
?
    N

FEE INCREASE   TOTAL VISITS
                                                              (SUMMARY REPORT WITH NEW
          .000             1869.33                            CUTOFF POINTS)
          .686             1766.80
         1.373             1568.98
         2.059             1482.92
         2.746             1401.59
         3.432             1180.58
         4.118              975.50
         4.805              922.00
         5.491              871.43
         6.178              823.64
         6.864              778.46
         7.550              735.77
         8.237              657.40
         8.923              621.34
         9.610              587.26
        10.296              514.24
        10.982              482.04
        11.669              432.23
        12.355              328.86
        13.042              144.34
```

SECOND STAGE DEMAND CURVE

COST INCREASE (DOWN) BY TOTAL VISITS (ACROSS)



```
CONSUMER SURPLUS =      11766.19                         (CONSUMER SURPLUS
C.S./TRIP =                 6.29                         ESTIMATES WITH CUTOFF
                                                         POINTS IN EFFECT)

 ADDITIONAL FEE     REVENUE    CHANGE IN REVENUE
            .69     1212.73              1212.73
           1.37     2153.89               941.16
           2.06     3053.64               899.74
           2.75     3848.20               794.57
           3.43     4051.74               203.53         (NEW FEE REVENUE TABLE)
           4.12     4017.51               -34.22
           4.80     4430.03               412.51
           5.49     4785.20               355.18
           6.18     5088.09               302.89
           6.86     5343.36               255.27
           7.55     5555.32               211.96
           8.24     5414.85              -140.47
           8.92     5544.35               129.50
           9.61     5643.35                99.01
          10.30     5294.66              -348.70
          10.98     5337.88                43.22
          11.67     5043.62              -294.26
          12.36     4063.13              -980.49
          13.04     1882.40             -2180.73


  ENTER OPTION (0 FOR MENU)
?
            0

1) INPUT DATA
2) DISTANCE TO COST CONVERSION
3) MODIFY DATA
4) RUN REGRESSIONS AND REPORTS
5) EXIT RMTCM PROGRAM
  ENTER OPTION (0 FOR MENU)
?                                                        (EXIT RMTCM)
            5

  SAVE DATA AS RMTCM SYSTEM FILE         ? (Y OR N)
?
   Y
  ENTER NAME OF RMTCM SYSTEM FILE
?                                                        (SAVE DATA AS RMTCM
   TABLE1.SYS                                            SYSTEM FILE)
   12 CASES WERE SAVED ON FILE TABLE1.SYS                (THE FILE NAMES IN THE
                                                         “$AVE DIALOG USE PERIODS (“.”)
                                                         ON THE PC AND DASHES (“-”) ON
LOG OF SESSION HAS BEEN SAVED ON FILE ‘TCM.LOG’          THE UNIVAC: “TABLE1.SYS”
                                                         ON THE PC IS “TABLE1-SYS”
END OF TCM PROGRAM                                       ON THE UNIVAC)
```

Rosenthal, Donald H., Dennis M. Donnelly, Marie B. Schiffhauer, and Glen E. Brink. 1986. User's Guide to RMTCM: Software for Travel Cost Analysis. USDA Forest Service General Technical Report RM–132, 32 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

RMTCM is an interactive menu-driven program for performing travel cost analysis. The program consists of four main modules: (1) data input; (2) data modification; (3) regression analysis; and (4) report writing. The report graphs the "second-stage" demand curve and estimates consumer surplus. The program is written in FORTRAN-V and a version is available for use on an IBM personal computer or compatible machine.

Keywords: travel cost model, computer program, consumer surplus

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-133**

Range Forage Data Base for 20 Great Plains, Southern, and Western States

Linda A. Joyce, David E. Chalk, and Andrew D. Vigil

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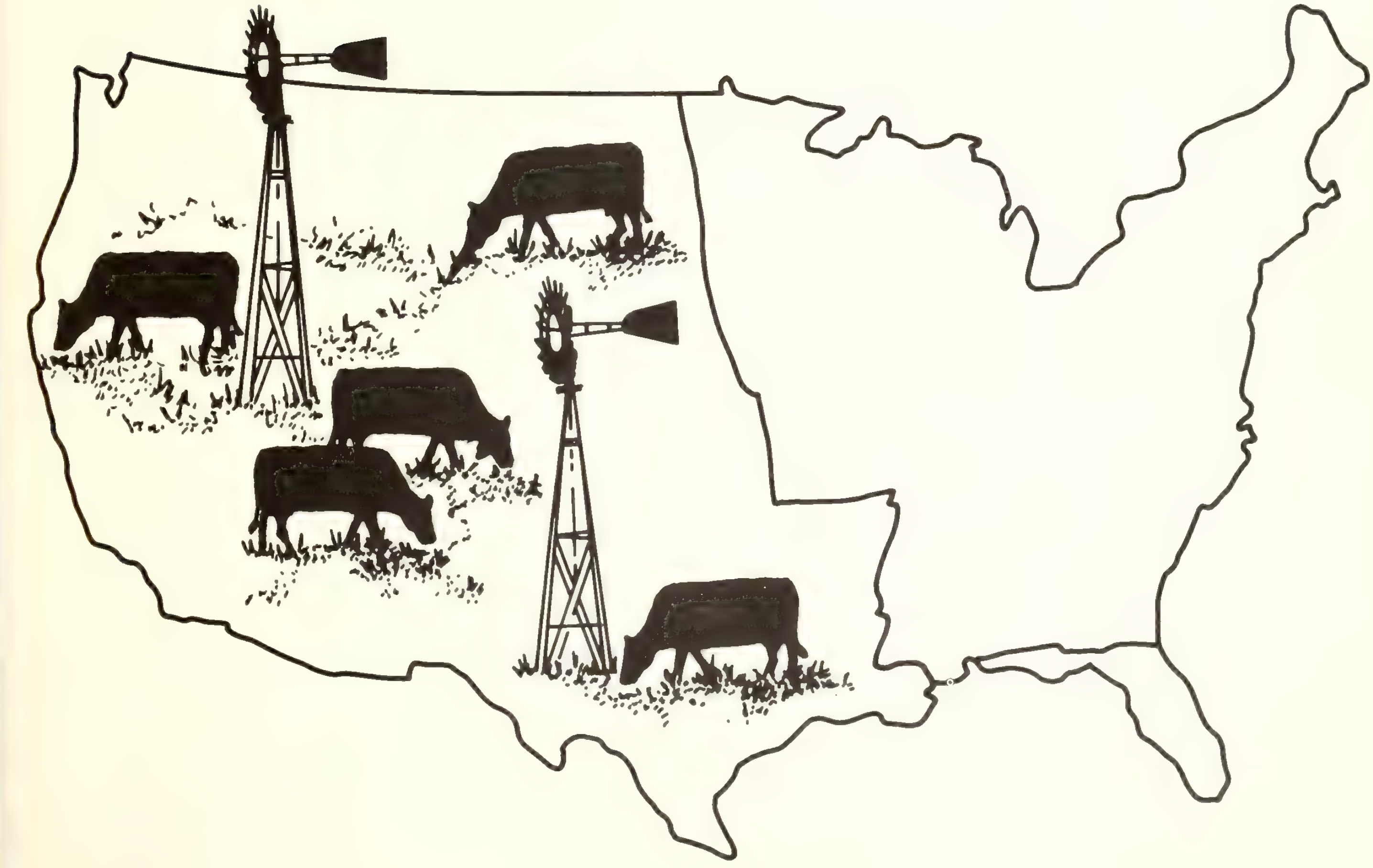

Abstract

This paper documents the development and structure of the RANGE FORAGE data base, a subset of information from all Soil Conservation Service Range Site Descriptions for 20 states: Arkansas, Arizona, California, Colorado, Florida, Idaho, Louisiana, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, Wyoming. Information in the data set includes range site name, location identifiers, total annual production, soils information, and initial stocking level rates. Data is accessible via tape from the USDA Fort Collins Computer Center. This data can be used to analyze range site productivity within a state, between states or across regions.

USDA Forest Service
General Technical Report RM-133

September 1986

Range Forage Data Base for 20 Great Plains, Southern, and Western States

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David E. Chalk, Biologist
Soil Conservation Service
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---

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Range Forage Data Base for 20 Great Plains, Southern, and Western States

Linda A. Joyce, David E. Chalk, and Andrew D. Vigil

MANAGEMENT IMPLICATIONS

This report describes the content and accessibility of a rangeland data set based on the Soil Conservation Service (SCS) Range Site Descriptions. A range site is an ecological subdivision of the landscape based on the ability of that site to produce a characteristic natural plant community (USDA Soil Conservation Service 1976). Range Site Descriptions were developed by SCS to help plan and carry out resource conservation programs on rangeland and other native grazing land. Previously, Range Site Descriptions were available within each state SCS office in written form only. A subset of the information available in each Range Site Description was extracted and placed on a computer for use in the periodic national assessment of rangelands and forestlands by the Forest Service (see USDA Forest Service 1980 for a description of the 1979 Assessment). This rangeland data set describing herbaceous production and stocking rates by range sites will be linked to an inventory data base and will be used to project the supply of grazing on rangelands.

RANGE FORAGE, the rangeland data, contains a subset of information taken from all SCS Range Site Descriptions for 20 states: Arkansas, Arizona, California, Colorado, Florida, Idaho, Louisiana, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming. This information includes: range site name, location identifiers, soils information specific to the range site, Soils Interpretation Record number associated with the soil taxonomic unit, total annual production in pounds per acre, and animal stocking guide in acres/animal unit months. Because Range Site Descriptions are standardized in form only, not content, at the national level (USDA Soil Conservation Service 1976), this report documents the differences between states with respect to this subset of information taken from the Range Site Descriptions. This data set is accessible to the reader via a tape at the USDA Fort Collins Computer Center in Colorado.

Information contained within each range site description could be analyzed within a state or across states within a region. Herbaceous production estimates and stocking levels could be used to quickly evaluate range site potentials within soil type groups, for example. Such an analysis would facilitate range site-soil type correlations between states. Regional variations in herbaceous production have been examined using this data set (Sala et al. 1985). The data also could be used as a starting point to automate revisions of existing Range Site Descriptions and the development of new Range Site Descriptions.

INTRODUCTION

A range site is a characteristic natural plant community typified by an association of plant species that differ from other range sites in either the kind or proportion of species or in the total standing crop of biomass produced on the site (USDA Soil Conservation Service 1976). The range site descriptions define a site as a function of environmental factors including climate, physiography, soils, and the plant community. Descriptions of range sites are used as the basic ecological data for planning the use, development, rehabilitation, and management of rangeland. The development of a Range Site Description is standardized at the national level by the procedures outlined in the National Range Handbook (USDA Soil Conservation Service 1976). Individual range site descriptions are developed within each state and are unique to that state.

The objective of this work is to compile a national level data base on range productivity. Data used to assess the U.S. rangeland production must be nationally consistent and represent current range management. Information contained in the range site descriptions meets both criteria.

In order to link RANGE FORAGE to other national level data sets, common data elements must be present. Other national level data sets of interest include the 1981–1982 SCS Natural Resources Inventory (NRI), the Soil Interpretation Records (USDA Soil Conservation Service 1983), and the Map Unit Use File (USDA Soil Conservation Service 1983). Linkage with the NRI required inclusion of the Major Land Resource Areas (MLRAs) (USDA Soil Conservation Service 1981) associated with each range site, because MLRAs are also used to identify NRI sample points. Only rangeland and soil type were used to identify the NRI sample point for which range condition was taken; thus, soil taxonomic units associated with each range site were included in the RANGE FORAGE data base. Many soil series can be associated with one range site. A range site in Nebraska may have as few as 1 or as many as 17 soil taxonomic units associated with it. Thus, the combination of MLRA, soils, and range sites for a state will be much greater than the number of range sites only. A state such as Nebraska, which has 80 range sites, has 4,381 MLRA-range site-soil combinations. These combinations are referred to here as range site-soils combinations.

STRUCTURE OF RANGELAND DATA

A standard set of information (table 1) was taken from all range site descriptions available as of 1984 for each

Table 1. Range site information contained within the RANGE FORAGE data base.

- Geographic Location Identifiers
  - State
  - Region
  - Major Land Resource Area
  - Unique state land division codes
  - Precipitation (inches)
- Range Site Name
- Soil Information
  - Soil Taxonomic Unit Name
  - Texture, texture modifiers, and phase/class description
  - Slope
  - Soil Interpretation Record Number
- Total Annual Production (lb/acre)
- Initial Stocking Rates (AUMs)

of these 20 states: Arkansas, Arizona, California, Colorado, Florida, Idaho, Louisiana, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming. The major categories included geographic location identifiers, range site name and identifiers, soil descriptions, total annual production and initial stocking rates. Information available within each range site varied by state. For example, some states used land divisions unique to that state rather than the MLRAs to describe the broad geographic location of the range site. Typical soil taxonomic units usually were given in each range site description. Additional information concerning soil texture, texture modifiers, and phase/class descriptions were included in RANGE FORAGE only if such information defined the range site.

Geographic Location Identifiers

Most states identified broad geographic locations for the occurrence of the range sites using the Land Resource Regions and MLRAs of the United States (USDA Soil Conservation Service 1981). Region is described by a 1-letter alphabetical code, such as F, for the Northern Great Plains Spring Wheat Region, and a 3-number code described the Major Land Resource Area within the Region, such as 53 for the Dark Brown Glaciated Plains MLRA within Region F (USDA Soil Conservation Service 1981). Subresource areas have been identified for some MLRAs, and are coded by a 1-letter alphabetical code, such as A for Northern Dark Brown Glaciated Plains, and B for Central Dark Brown Glaciated Plains. The 1978 map and 1981 documentation of MLRAs and Regions provide a national description of this land system, and state MLRA maps are also available for some states.

Additional subresource areas not on the 1978 map and missing subresource areas for MLRAs which had subresource areas on the 1978 map were handled as follows. If the range site description provided a MLRA and a subresource area, but the subresource area was not on the national map, the subresource area was coded into the data base. A more refined map of the state would be necessary to define the boundaries of this subresource area. If the range site description gave only the MLRA 36, for example, and the 1978 national map defined subresource areas (i.e., 36A and 36B) then the subresource area was considered to be missing and was assigned according to this procedure. If MLRA 36A only occurred in the state (and not 36B) then the range site was assigned MLRA 36A. However, if both 36A and 36B were found in the state, and the range site description did not specify any locations, either by county or other state subdivisions, then the range site was assigned the MLRA 36. If the description did specify locations then the MLRA which fell within those locations was assigned to the range site.

North Dakota, Wyoming, and Nebraska used land division codes unique to their states; these codes were retained in RANGE FORAGE. Several states used additional state divisions. Texas was divided into potential evapotranspiration (PE) classifications.

Precipitation zones were used to define the average annual precipitation in inches. If low and high values were given, then both values were coded. If only one value was given, it was coded according to whether it was a greater than or less than value. If 20 inch plus was given, indicating the precipitation was greater than or equal to 20 inches, it was coded in the low precipitation column. If <20 inches was given, it was coded in the high precipitation column indicating 20 inches as a maximum value.

Soils Information

Range site descriptions reported typical or major soil taxonomic units associated with each range site. Soil taxonomic units varied from soil series to order to soil mapping unit, with most range sites described by one or more soil series.

If texture was used to further specify soil type, it was coded using SCS standard abbreviations shown in Appendix 3 (USDA Soil Conservation Service 1983). If a texture modifier was used to further specify soil texture, it was coded using SCS standard abbreviations shown in Appendixes 3 and 4 (USDA Soil Conservation Service 1983). If slope was used to further define the soil type, it was included into the data base. High and low values were coded in the same manner as the precipitation values.

If the phase/class description was used to further define soil type, it was coded using SCS standard abbreviations shown in Appendix 4 (USDA SCS 1983). If the phase/class did not have a standard abbreviation, the entire description was recorded. This category also was used to describe some soil variations, such as Hardpan. Textural modifiers given in parentheses in the descriptions also were placed in this category.

The Soil Interpretation Record Number, commonly called the Soils 5 number, was included to link this data base with other national level data bases, such as the SCS NRI. Soils 5 numbers are associated with soil series, families, and orders, varying by state (USDA Soil Conservation Service 1983). This number was not given in the individual range site descriptions. The Soils 5 numbers for individual soils were obtained from the Iowa State University data base in June 1984.

Because range site soil descriptions using series and texture may not correspond exactly with series defined in the Soil Interpretation data base, a procedure was developed to assign Soils 5 numbers to these soil series. If the range site description contained a soil series with a texture specification but the Soil Interpretation Record data base contained the soil series without a texture assignment, then that Soils 5 number was assigned to the soil series in RANGE FORAGE. If the Soils 5 list contained the same series but a different texture, no number was assigned to the soil series in this data base. If the Soils 5 list contained the same series and texture as the range site, but had a modifier such as "very" (e.g., very gravelly), then that Soils 5 number was assigned to the soil series in this data base. The Soils 5 number may represent a more general class of texture than the range site description, and the actual texture given in the Description (and coded into this data base) should be checked when the Soils 5 numbers are used. Any correspondence between texture and productivity should use the texture values coded with the soils in this data base, not the Soils 5 numbers.

Production Information

Total annual production was given in air dry weight as pounds per acre on an excellent condition site for favorable and unfavorable years, as well as the median year. Any information given in the guides on the development of these estimates was included in the discussion of each state range site descriptions.

Range site descriptions gave stocking rates to guide the initial stocking of domestic livestock on a site. Initial stocking rates were coded into this data base as acres per animal unit month (AUM) by condition class. Condition class definitions were standard: excellent = 76–100% of the climax vegetation, good = 50–75% of the climax vegetation, fair = 26–50% of the climax vegetation, and poor = 0–25% of the climax vegetation. If stocking rates were given by favorable and unfavorable years and not by condition classes, no values were coded. If stocking rates were given by favorable and unfavorable years, and by condition classes, then the favorable year values by condition classes were coded into this data base.

If stocking rates were given as a range from low to high acres per AUM, then the low and the high values of the range were coded into RANGE FORAGE. Stocking rates for the poor condition class usually were recorded as N+ acres/AUM, implying that the stocking level should be greater than N acres. This value was always coded in the low end of the poor condition stocking rate columns. If stocking rates were given as a single number for each condition class, then that single number was coded in the low columns for each condition class. The high value of the range was left blank; no value was coded.

RANGE SITE DESCRIPTIONS BY STATE

The data contained within the range site descriptions across states is summarized in table 2. Information content of range sites descriptions varied by state. Assumptions associated with data from range sites by states are described in the individual state descriptions.

Table 2.—Information reported in the range site descriptions by state.

State	Number Range Sites	Annual Production	Stocking Level	Soils	Number of Combinations	Year of Report
Arkansas	44	X		X	1952	1962
Arizona	276	X	X	X	1585	1982
California	189	X	-	X	1448	1964-80
Colorado	151	X	X	X	1134	1975-84
Florida	13	X	X		13	1983
Idaho	265		X	-	1279	1971-82
Kansas	63	X	X	X	428	1982-84
Louisiana	2	X	X	X	4	
Montana	122	X	X	X	382	1978-81
Nebraska	80	X	X	X	4381	1981
Nevada	210	X		-	216	1981-83
New Mexico	202	X	X	X	990	1977-83
North Dakota	59	X	X	X	626	1975-84
Oklahoma	100	X		X	688	1960-71
Oregon	226	-	X	X	534	1968-81
South Dakota	84	X	X	X	947	1979
Texas	827	-	-	-	2535	1972-81
Utah	84	X		X	2537	1971-78
Washington	25	X	X	X	581	1981-83
Wyoming	250	X	X	-	756	1977-81

X all range sites
- some range sites

Arizona

Arizona had a total of 276 range sites[2] identified by Region, MLRA, and subresource area. Precipitation zones were recorded with each range site. In contrast with other states where topography was more homogenous, MLRAs sometimes had more than one precipitation zone.

Soils Information

The number of major soils associated with each range site varied from 1 to 12. Soil series were given most commonly; but in some cases, the family or order was given. For some soils, several textures were associated with that soil and range site. Soils 5 numbers were available for approximately 90% of soil taxonomic units. Only one range site did not have a representative soil: Volcanic hills 2 to 7 inch precipitation zone (p.z.) MLRA 30, 31.

Total annual production for an excellent condition site was given for all range sites in pounds of air dry herbage per acre for favorable, unfavorable, and normal years.

Initial Stocking Rates

Initial stocking rates were given as a guide to establishing a safe starting stocking rate, with the caution that the stocking level and the livestock numbers should be adjusted based on actual use experience and climatic fluctuations. The units are acres per AUM, consistent with all other states in this data base.

Some range site descriptions did not report stocking levels. For Saline Bottom and Saline Subirrigated, the variability of production and dominance of nonforage plants was such that stocking rates could not be predictably estimated. For Breaks, 7 to 12 inch p.z., the range site guide states that this site is not normally grazed and does not occupy a significant portion of range. Therefore, a stocking allowance should not be made because it would encourage overuse of adjacent sites. For Breaks, 10 to 14 inch p.z., the guide states that the stocking rates are extremely variable and are a function of slope, rock and brush condition. For Limy Upland, 7 to 10 inch p.z., because the guide does not give an estimate for stocking level for a poor condition site, this was left blank in the standard format—both high and low estimates.

Arkansas

Arkansas had a total of 44 Range Site Descriptions[3] identified by Region and MLRA. The range sites were all dated 1962 and represent the soils classification in use at that time.

Soils Information

Each range site description reported significant soils associated with that range site. These soils are from an older soils classification, and the texture descriptions were non-standard with respect to this data base. Thus, the soils were coded as they were described in the range site description; but the texture descriptions were redefined using the SCS standard definitions. The Arkansas original texture codes and their translation in this data base are given in table 3.

Slopes for Arkansas were taken from the topography section of the range site descriptions and described general conditions for the range site. No slopes were used in the Arkansas range site descriptions to define range sites.

Total Annual Production

Total annual production was reported as a range of annual herbage yield for all range sites. The lower end of the range was coded as production in unfavorable years and the upper end as production in favorable years.

Initial Stocking Rates

No initial stocking rates were given.

California

California had 189 Range Site Descriptions[4] identified by Region, MLRA, and subresource areas. California used additional subresource areas that were not on the 1978 map and counties to further subdivide the state. The Subresource areas represent Land Resource Area Evapotranspiration Zones. The evapotranspiration codes appear within the range site name for several range sites. All range site-soil combinations were coded with a subresource area within the MLRA code. Range sites were specific to a county in California in fewer than 2% of the cases, and county was not recorded in this data base.

Soils Information

Most range sites had soil mapping units or soil series names given in the taxonomic group. Soil mapping unit numbers given in the guides were not coded into this data base. Soils 5 numbers associated with soil series were available for most soils. Range sites without associated soils included Loamy Hardpan 10 to 12 inch and 12 to 14 inch MLRA 21D, North Slope Shallow Coarse Loamy, North Slope Shallow Loamy, North Slope Shallow Stony Loam 14 to 16 inch and 14 to 16 inch, North Slope Stony Loam, Shallow Coarse Loamy 14 to 16 inch MLRA 21D, Shallow Loamy 10 to 12 inch and

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[2] *On file at SCS State Office: Range Conservationist, SCS, Suite 200, East Indianola, Phoenix, Ariz., 85012.*

[3] *On file at SCS State Office: Range Conservationist, Federal Office Building, Room 2405, 700 West Capitol Avenue, Little Rock, Ark. 72201.*

[4] *On file at SCS State Office: Range Conservationist, SCS, 2828 Chiles Road, Davis, Calif. 95616.*

Table 3.—Translation of Arkansas soil texture and texture modifiers into the standard abbreviations used for all states.

Arkansas Codes	Texture term	Modifier code	Texture code	Phase/class code
CHSIL	Cherty silt loam	CR	SIL	-
CHL	Cherty loam	CR	L	
COCHSIL	Coarse cherty silt loam	CRC	SIL	
COL	Coarse loam	-	COL	
CO	Coarse	-	CO	
FSLS	Fine silt loam-silt	-	FSL	Silt
FSLM	Fine silt loam mounded	-	FSL	Mounded
FCHSIL	Fine cherty silt loam	FCR	SIL	
GC	Gravelly clay	CR	C	
GVFSL	Gravelly very fine sandy loam	CR	VFSL	
GFSL	Gravelly fine sandy loam	GR	FSL	
GSICL	Gravelly silty clay loam	GT	SICL	
GSIL	Gravelly silt loam	GR	SIL	
GL	Gravelly loam	GR	L	
GLFS	Gravelly loamy fine sand	GR	LFS	
GSL	Gravelly sandy loam	GR	SL	
GSTFSL	Gravelly and stoney fine sandy loam	GR	FSL	Stony
GSTSL	Gravelly stoney sandy loam	GR	SL	Stony
GLS	Gravelly loamy sand	GR	LS	
LSM	Loamy sand mound	-	LS	Mounded
LSUB	Loamy subsoil	-	L	Subsoil

12 to 14 inch, Shallow Stony Loam 10 to 12 inch and 12 to 14 inch, Stony Loam 10 to 12 inch and 12 to 14 inch, Very Shallow Stony Loam 10 to 12 inch and 12 to 14 inch.

Total Annual Production

Total annual production was given in pounds per acre for most range sites for favorable and unfavorable years. The more recent range site descriptions also included normal year production.

The guide states that the Steep Gravelly Loam range site in MLRA 15D and the Steep Loamy range site in MLRA 15D and 15E has very low potential for livestock grazing, because these soils have naturally dense brush with very steep slopes, making accessibility very difficult. No annual production or stocking rates were given for this range site. Total annual production for Gravelly Loam MLRA 18D was reported as current year's growth, air dry herbage production only. No annual production was given for Shallow Coarse Loamy MLRA 21 and MLRA 26; this site provides a small amount of usable forage for livestock. It is accessible; but the guide reports a shortage of water on this site.

Many of these range sites have a large amount of unusable forage for domestic livestock. Thus, the total annual production represents total production. The usable portion could be less than 50% of this total. A few of the range sites gave the useble forage present, either based on the proper grazing use of key species by livestock and/or wildlife (Clay Basins range site 10 to 12 inch, and 12 to 14 inch MLRA 21D) or based on leaving a set amount of mulch for soil protection and forage production (Clayey Bottomland MLRA 14 and 15), or based on leaving a set amount of mulch for soil protection and forage production and adjusting for the slope (Coastal Gravelly Loam MLRA 15). Stocking rates become important in interpreting the domestic livestock use on each site.

Initial Stocking Rates

The coastal regions, Sacramento and San Joaquin Valleys, Sierra foothills, and Southern California Coastal Plains (MLRA 5, 14, 15, 17, 18, 19) did not give initial stocking levels by condition classes. Stocking rates for these MLRAs were commonly reported for favorable, normal, and unfavorable years. These values were not coded into the data base.

Range site guides for MLRAs 21, 22, 23 and 26 reported initial stocking levels by condition classes. All range sites within MLRA 21D have initial stocking rates except range site Stony Loam (the major portion of this site is not grazed by livestock because of the steep slopes and stoniness). In MLRA 22, all range sites had initial stocking rates except Semiwet Meadow (stocking rates given in favorable and unfavorable years).

Colorado

Colorado had 151 Range Site Descriptions[5] identified by Region and MLRA. Range sites dated 1980 and after are coded in this data set with the Colorado range site number in the range site name.

[5] *On file at SCS State Office: Range Conservationist, SCS, Diamond Hill, Bldg A, 3rd Floor, 2490 West 26th Avenue, Denver, Colo. 80211.*

Soils Information

Soil series was the most common soil taxonomic unit used, and the Soils 5 number was available for 95% of the sites. For a small number of sites, the soil taxonomic units included a general characterization of soils, such as Alluvial Land complex for range site Loamy Plains in MLRA 69B, and Wet Alluvial Land in range site Wet Meadow in MLRA 67. These general characterizations were coded into the soil taxonomic unit category in this data base but do not have Soils 5 numbers. No soils were given for these 16 range sites: Loamy Breaks in MLRA 34 and 48; Limestone Hills in MLRA 47, 48 and 34; Loamy Slopes in MLRA 47, 34 and 48; Shallow Slopes in 48; Sandy Saltdesert in 34, 35, 37; Clayey Saltdesert in MLRA 34, 35; Saltdesert Breaks in MLRA 34, 37.

Total Annual Production

Total annual production was given for favorable and unfavorable years as well as the median year. All range sites had total annual production values.

Initial Stocking Rates

Initial stocking rates were given by condition class for range sites dated after 1980. For range sites dated before 1978, no stocking rates were given. Initial stocking rates were based on an average growing season, and 1200 pounds of forage (air-dry) per AUM. This figure accounts for vegetation that disappears through trampling, small herbivores, etc., which the guide states averages approximately 7.9 pounds per day under normal conditions.

Florida

Thirteen range sites were described in Florida[6]. No substate divisions were used and no representative soils were given. Thus, there are 13 range site-soil combinations for Florida.

Soils Information

Soils were described for each site but no representative soils were named in the range site descriptions.

Total Annual Production

The average annual production of air dry plant material was reported for favorable years and unfavorable years for all range sites.

Initial Stocking Rate

Initial stocking rate was reported by condition class for each range site in acres/animal unit. This was assumed to represent year-long grazing; therefore, this value was divided by 12 to obtain a monthly value: acres per AUM. On forested range sites, the forest overstory affects the initial stocking rates. On all forested range sites, if the canopy cover exceeds 60%, there will be little or no grazing. For range sites Cutthroat Seep, Everglades Flatwoods, Longleaf pine-turkey oak hills, North Florida Flatwoods and South Florida Flatwoods, the stocking rates should be reduced by 10% for every 15% over 25% canopy cover. For Upland Hardwood Hammocks, stocking rates should be reduced 10% for every 15% over 35% canopy cover. On Sand Pine Scrub, the stocking rates should be reduced 10% for every 15% over 40% canopy cover. Values coded into the data base represent the base value.

Idaho

Idaho has 265 Range Descriptions[7] identified by Region and MLRA. Precipitation zones were used to subdivide MLRAs. Plant community descriptions were given for most range sites. The descriptions included dominant species (up to three) abbreviated with the 4-letter code (first 2 letters of genus and species). For example, Shallow Stony 16 to 22 inch p.z. range site has plant community AGSP/FEID which is bluebunch wheatgrass and Idaho fescue. There are occasionally range sites occurring in the same MLRA and precipitation zone with different plant communities. For example in MLRA 10A and the 12 to 16 inch precipitation zone, Clayey range site occurs as Clayey ARTRY/AGSP (threetip sagebrush/bluebrush wheatgrass) and Clayey ARLO/FEID (alkali sagebrush/Idaho fescue).

Range sites without plant communities were: Wet Meadow Saline MLRA 28; Steep Slopes 16 to 22 inch p.z. MLRA 47; Loamy 22 inch plus p.z. MLRA 47; Shallow Loamy (Mahogany) 16 to 22 inch p.z. MLRA 43, 47; Gravelly 8 inch p.z. MLRA 11B, 12, 28; Shallow Fractured 7 to 12 inch MLRA 11B; Dense Clay 12 to 16 inch p.z. MLRA 25, 28, 47; Loamy 16 to 22 inch p.z. MLRA 25, 28, 47; Riverbottom MLRA 25, 28, 47; Stony 8 to 12 inch p.z. MLRA 25, 28; Stony 12 to 16 p.z. inch, MLRA 47.

Soils Description

Twenty-five percent of the range sites were missing soil series names. The Soils 5 number was available for most soil series.

Total Annual Production

Production was given as air dry average annual production for favorable, median, and unfavorable years in pounds per acre. Only two range sites did not have annual production estimates: Loamy MLRA 11 and Semiwet Meadow MLRA 25.

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[6] *On file at SCS State Office: Range Conservationist, SCS, 401 S.E. First Avenue, Gainesville, Fla. 32601.*

[7] *On file at SCS State Office: Range Conservationist, SCS, 304 North 8th Street, Room 345, Boise, Id. 83702.*

Initial Stocking Rates

No initial stocking rates were given.

Kansas

Kansas had 63 Range Site Descriptions[8] identified by Region and MLRA. Precipitation ranges were given by MLRA and this information was coded in this data base. These 63 range sites represented the currently revised range site guides for Kansas.

Soils Information

From 1 to 10 characteristic soils were given for each range site. Soils 5 numbers were also available as series was the most common soil taxonomic unit. Some range sites had characteristic soils such as alluvial land, or complexes which were coded into the soil taxonomic unit category and these do not have Soils 5 numbers. Some soils were occasionally to frequently flooded. This was coded in the phase/class description according to the abbreviations in appendix 4: OCCAS to FREQ.

Total Annual Production

For all range sites, total annual production was given for favorable, unfavorable and normal years for an excellent condition site. These production figures were based on available clipping data. The guide notes that the vigor of principal forage species, time of burning if fire is used, and growing conditions, will influence annual herbage production. Only normal year production was reported for the Saline Subirrigated range site because the subirrigated condition tends to nullify the effect of precipitation.

Initial Stocking Rate

For all range sites, initial stocking rates were given by condition class. Values were given for Acres/AU year-long, and AUM per acre. A range was given for Acres/AU year-long and, only one value for AUM per acre (the high value of Acres/AU transformed). As a range of values were desired for this data base, the Acres/AU year-long grazing values were used here. Because these values represented year-long grazing, the rates were divided by 12 to obtain Acres per animal unit month which then were stored in the data base. These guidelines were described in the range site description as safe initial stocking rates from which a sound management program could be built. The guide notes that grazing only during the dormant season or use of a specialized grazing program may allow an increase in the stocking rate.

Louisiana

There were two range sites described for Louisiana[9]. Both sites occurred in the Gulf Coast Marsh MLRA. One site had one soil and the other site had three soils associated with it; thus there were four range site-soil combinations for Louisiana.

Soils Information

Representative soils were given for each range site. As soil series were given, the Soils 5 numbers were available also.

Total Annual Production

Total annual production was given as air-dry herbage by condition class rather than by climatic year. For this data base, the excellent condition herbage production was coded in the favorable year category and the poor condition range in the unfavorable year category. No median year value was given.

Initial Stocking Rates

Initial stocking rates were given by condition class for all range sites.

Montana

There are 122 Range Site Descriptions[10] identified by Montana Land Divisions and precipitation zones within the Land Divisions. There are 9 divisions in the Montana Land divisions (table 4). Regions and MLRAs were not used to subdivide Montana.

Soils Information

The number of soils associated with each range site varied from 1 to 7. Series were the most common unit. Soils 5 numbers were available for most of these soils. The 21 range sites that do not have soils are: Panspots (EGP), Shale (EGP) (this site provides very little forage for grazing animals), Very Shallow (EGP 10 to 14 inch p.z.) (this site provides limited forage for grazing animals), Sands (ESP 15 to 19 inch p.z.), Shallow Clay (ESP 15 to 19 inch p.z.), Thin Breaks (ESP 10 to 14 inch p.z.), Wet Meadow (ESP 10 to 14 inch p.z.), Very Shallow (ESP 15 to 19 inch p.z.), Stony (FM 10 to 14 inch p.z.), Very Shallow (FM, 20 inch plus p.z.) (this site has limitations for livestock because of inaccessibility and short growing season), Panspots (WGP 10 to 14 inch p.z.),

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[8] *On file at SCS State Office: Range Conservationist, 760 S. Broadway, Salina, Kans. 67401.*

[9] *On file at SCS State Office: Range Conservationist, SCS, 3737 Government Street, Alexandria, La. 71301.*

[10] *On file at SCS State Office: Range Conservationist, SCS, 32 E. Babcock, Bozeman, Mont. 59715.*

Table 4.—Montana Land Divisions, precipitation zone, and code used in the standard format.

Land division	Precipitation (inches)	Code
Eastern Glaciated Plains	10–14	EGP
Eastern Sedimentary Plains	10–14	ESP
Eastern Sedimentary Plains	15–19	ESP
Western Glaciated Plains	10–14	WGP
Foothills and Mountains	10–14	FM
Foothills and Mountains	15–19	FM
Foothills and Mountains	20+	FM
Western Sedimentary Plains	5–9	WSP
Western Sedimentary Plains	10–14	WSP

Shale (WGP 10 to 14 inch p.z.) (this site provides little forage for grazing animals), Shallow Clay (WGP 10 to 14 inch p.z.), Clayey (WSP 5 to 9 inch p.z.), Gravel (WSP 10 to 14 inch p.z.) (low grazing values because of lack of production), Panspots (WSP 10 to 14 inch p.z.), Saline Upland (WSP 10 to 14 inch p.z.), Sands (WSP 10 to 14 inch p.z.), Shallow to Gravel (WSP 10 to 14 inch p.z.), Thin Breaks (WSP 10 to 14 inch p.z.), Very Shallow (WSP 10 to 14 inch p.z.).

Total Annual Production

All but 2 of the 122 range sites have total annual production reported as air dry weight in pounds per acre on excellent condition ranges in favorable, unfavorable, and median years. The Silty range site in ESP 15 to 19 inch p.z. reported only favorable and unfavorable years, and the Subirrigated range site in WSP 10 to 14 inch p.z. did not report annual production.

Initial Stocking Rates

Initial stocking rates were given for all range sites in Montana by condition class.

Nebraska

Nebraska had 80 Range Site Descriptions[11] identified by Nebraska Vegetation zones, Regions, and MLRAs. Nebraska Vegetation zones are the former Nebraska Precipitation zones (table 5).

Soils Information

The number of major soil taxonomic units associated with each range site varied from 1 to 17. Soil series were given most often for the taxonomic unit and thus the Soils 5 numbers were available for most soils. Texture definitions were usually given with the soils.

Total Annual Production

Total annual production in excellent range condition was defined for all range sites. Average production for below average conditions, average conditions and above average conditions were given for most range sites. Production values for the average condition were missing for a few range sites.

Initial Stocking Rates

Initial stocking rates were given for all range sites by condition class.

Nevada

Nevada had 210 Range Site Descriptions[12] identified by MLRA. Precipitation zones were used to subdivide the MLRAs.

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[11] *On file at SCS State Office: Range Conservationist, SCS, Federal Building, Room 345, 100 Centennial Mall North, Lincoln, Nebr. 68508.*

[12] *On file at SCS State Office: Range Conservationist, SCS, 50 South Virginia Street, Reno, Nev. 89505.*

Table 5.—Nebraska Land Division Codes.

Zone	Counties
I	Sioux, Box Butte, Scotts Bluff, Morrill, Banner, Kimball, Cheyenne
II	Dawes, Sheridan, Cherry, Garden, Grant, Hooker, Thomas, Arthur, McPherson, Logan, Deuel, Keith, Lincoln, Perkins, Chase, Hayes, Frontier, Dundy, Hitchcock, Redwillow
III	Keya Paha, Boyd, Brown, Rock, Holt, Blaine, Loup, Garfield, Wheeler, Custer, Valley, Greeley, Sherman, Howard, Dawson, Buffalo, Hall, Gosper, Phelps, Kearney, Adams, Clay, Furnas, Harlan, Franklin, Webster, Nuckolls, Knox, Cedar, Dixon, Antelope, Pierce, Wayne, Boone, Nance, Merrick, Hamilton
IV	Dakota, Thurston, Madison, Stanton, Cuming, Burt, Platte, Colfax, Dodge, Washington, Polk, Butler, Saunders, Douglas, Sarpy, York, Seward, Lancaster, Cass, Otoe, Filmore, Saline, Thayer, Jefferson, Gage, Johnson, Nemaha, Pawnee, Richardson

Soils Information

Only one representative soil series was given for each range site. Only one-third of the sites had soils associated with them. In a few cases, several textures were given for the same soil. These descriptions range from soil series to families to orders. Soils 5 numbers were available for most series.

Total Annual Production

All range site descriptions reported total annual production in air-dry weight in pounds per acre for favorable, unfavorable years, and normal years.

Initial Stocking Rates

No initial stocking rates were given.

New Mexico

New Mexico had 202 Range Site Descriptions[13] identified by MLRA. In addition, subresource areas were used to further define range sites.

Soils Information

Most range sites with soil taxonomic units have the Soils 5 number. A few range sites had rock outcrop complexes or associations that do not have Soils 5 numbers. Out of the 990 combinations, only 12 range sites did not have a soil taxonomic unit: Loamy Savannah (D36A), Sandy (D36A), Mountain Shale (E48B), Bottomland (E51A and E51B), Dry Loamy (E51A), Gravelly loam (E51A), Salt Meadow (E51A and E51B), Gravelly Slopes (E51B), Limestone Hills (G70C), Shallow Plains (G70C).

Total Annual Production

All range site descriptions report total annual vegetation produced in average air-dry weight in pounds per acre for favorable and unfavorable years. About one tenth of the sites also include the average production.

Initial Stocking Rates

All 990 range site-soil combinations reported an initial stocking rate by condition class. The range sites dated 1978 reported stocking rates for favorable and unfavorable years. The favorable years were reported in this data base.

North Dakota

North Dakota had 59 Range Site Descriptions[14] identified by 8 Vegetation zones. Precipitation was defined for each Vegetation zone (table 6). No range sites were described for the Red River Valley vegetation zone. Range sites from the adjacent vegetation zones are to be used for this zone. Region and MLRA were not used to further divide North Dakota. Stocking Rate revisions dated April 1984 have not yet been incorporated into this data base.

Soils Information

Soil taxonomic units common to each range site were given for all range sites. The number of soil taxonomic units associated with each range site varied from 1 to 17. Commonly a range site was associated with a given soil and several textures. Soil series was used; therefore, the Soils 5 number associated with the series was available for all range sites. Occasionally, a general description of soils associated with the range site was given, (e.g., saline alluvial lands for the range site Saline Lowland). This soil taxonomic unit was coded in the data base under soil name; but no Soils 5 number would be available here. This data set may be missing the less common soil types within a range site.

Total Annual Production

Total annual production in excellent condition was given for all range sites in pounds per acre. A range of values were given representing the variability in growing conditions. No average values were reported.

Initial Stocking Rates

All range sites had recommended initial stocking rates based on condition classes given in the range site descriptions. Stocking rates were given for average years, recognizing that adjustments may be necessary to take into account local conditions, seasonal moisture levels, and inaccessibility. Tabular values recorded in this data base retain the assumption of continuous season-long grazing noted in the guide. Values in the guide were AUMs per acre, and these values were inverted to obtain acres/AUM prior to storing in this data base.

Oklahoma

Oklahoma had 100 Range Site Descriptions[15] identified by Region and MLRA. The table of contents (re-

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[13] *On file at SCS State Office: Range Conservationist, SCS, 517 Gold Avenue, S.W., Room 3301, Albuquerque, N. Mex. 87102.*

[14] *On file at SCS State Office: Range Conservationist, SCS, Rosser Avenue and Third Street, Federal Building, Room 270, Bismark, N. Dak. 58501.*

[15] *On file at SCS State Office: Range Conservationist, SCS Agricultural Center Building, Farm Road and Brumley Street, Stillwater, Okla. 74074.*

Table 6.—North Dakota vegetation zones.

Code	Vegetation Zone (inches)	Precipitation
1	Badlands (Wheatgrass-grama-stipa-artemisia)	13–15
2	Missouri Slope (Wheatgrass-stipa-grama)	15–16
3	Coteau (Wheatgrass-stipa-snowberry)	14–17
4	Central (Wheatgrass-stipa-snowberry)	16–18
5	Drift Prairie (Wheatgrass-bluestem-stipa-snowberry)	16–18
6	Border (Wheatgrass-bluestem-stipa-quercus)	16–18
7	Altamont (Wheatgrass-bluestem-stipa-snowberry)	17–20
8	Red River Valley (Bluestem-panicum-stipa) (no range sites were given for this zone)	18–20

vised 10/79)[15] shows a Loamy Prairie (40 inch plus p.z. Southern) but no range site description was available for this site.

Soils Information

Soils were described for all but one range site. The number of soils associated with each range site varied from 1 to 4. Occasionally, several textures were used to further specify a soil associated with a range site. Soil series were used for 50% of the range sites. Range sites also reported land types, such as alluvial land, subirrigated lowland, or broken land. These descriptions were coded in the soil taxonomic unit category and do not have Soils 5 numbers. Complexes were also reported under soils in the range site description. These soils also were coded in the soil taxonomic unit category and do not have Soils 5 numbers. The only range site without a soil unit was Loamy Plains in MLRA 78.

Total Annual Production

Production for all sites was reported by favorable and unfavorable years. Yields were estimated from limited clipping information. Sites such as Breaks GP, Breaks (40 inch plus p.z.) and Deep Sand Savannah Breaks (28 to 32 inch p.z.) reported values for herbaceous species and for woody species and a total. The values for woody species averaged 15% of the total in favorable years and 18% of the total production in unfavorable years. Only the total production value was recorded in this data base. Other range sites support a crown canopy cover of woody species ranging from 10% to 40% in the climax condition. For these sites, no woody species production was reported and production data was reported as total herbage yields in the guides.

Initial Stocking Rates

No initial stocking rates were given.

Oregon

Oregon had 226 Range Site Descriptions[16] identified by Region and MLRA. No other divisions were used to classify range sites. Sites with less than 15% tree canopy cover were described as range sites. Sites with tree canopy cover exceeding 15% were described as a Grazeable Woodland Site. Only sites described as range sites were coded into this data base. Sites with juniper as a dominant fell into the range site category, whereas, sites dominated by ponderosa pine were described as grazeable woodland sites and were not included in this data base. An attempt was made to incorporate the revisions noted on the range sites. For some MLRAs, range sites were not fully described. These sites were included into the data base to facilitate updating, but will not contain a complete set of information on production, soils or initial stocking levels.

Soils Information

Soils information was available for nearly all ranges sites in MLRAs 7, 8, 9, 21 and 43. Only 50% of the range sites in MLRAs 5, 10, 6, 23, and 24 had representative soils described. The number of soil taxonomic units associated with a range site varied from 1 to 10. Most soil taxonomic units were series and the Soils 5 numbers were available. Families, complexes and orders were also used to describe the soil taxonomic unit.

Total Annual Production

Less than one-third of the range sites reported a total annual production value. Average year production was given most often; however, some sites reported values for favorable and unfavorable years also.

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[16] *On file at SCS State Office: Range Conservationist, SCS, Federal Building, 16th Floor, 1220 S.W. Third Avenue, Portland, Oreg., 97204.*

Initial Stocking Rates

Stocking rates were given by condition class for nearly all range sites. On the Rough site, no stocking rate was given for the excellent condition range; therefore, both the low and the high values for excellent condition were left blank. On some sites, an initial stocking rate and a potential stocking rate (10–15 years of good management) were given. For this data base, only the initial stocking rate was coded.

South Dakota

South Dakota had 84 Range Site Descriptions[17] identified by Region and MLRA.

Soils Information

All range sites had significant soils described. The number of soils associated with each site varied from 1 to 13. For most sites, soil series was used. Thus, Soils 5 numbers were available. For Saline Lowland East Central in MLRA 53B, several soil series were given. In addition, the saline phase of other alluvial soils was also described as a significant soil for this range site. This soil type was coded into the soil taxonomic unit without a Soils 5 number. Similarly, for Saline Lowland Western in MLRA 58D, several soils were given as well as saline alluvial land. In Very Shallow Western in MLRA 60A, gravelly land was described as a significant soil. These general descriptions of soils were coded in the soil taxonomic unit without a Soils 5 number.

Total Annual Production

Total average annual air-dry production of the typical soil in each range site was given. The variation in herbage production from soil variability within each site was also given. Production variation as a function of climate was given as a percent of the average annual production. The increase from favorable climatic years varied from 10% to 20% higher than average. The decrease from unfavorable years varied from 30% to 40% less than average years. The increase in favorable years was about the same as the high end of the production resulting from soil variability. The decrease in unfavorable years was lower than the low end of the production resulting from soil variability. The range in production resulting from soil productivity, not climate related, was coded in the South Dakota data base. The variability from weather could be determined by applying a computation on the average total production.

Initial Stocking Rates

Initial stocking rates based on general averages were given as a guide in planning. Past grazing history may show that the rates suggested were too high or too low for a particular pasture. The guide notes that an on-site evaluation of all factors affecting grazing use within a pasture should be made before the initial stocking rate is proposed. Seasonal and annual variation in forage production will require timely adjustments in stocking rates to assure proper grazing use. Stocking rates were given in AUMS per acre by condition classes.

Texas

Texas had 827 Range Site Descriptions[18] identified by State Area, Region and MLRA. There are 27 State Areas. In addition, the state was divided into potential evapotranspiration (PE) zones, and range sites were associated with a PE zone. Sites described as Woodland Sites were not included in this data base. Eight sites from the Soil and Vegetation Groups described for Area 11 were not included, because grazing levels were defined by canopy classes.

Soils Information

Soil taxonomic units which characterize range sites were given for approximately two-thirds of the range sites. The number of soils associated with a range site varied from 1 to 8. Soil series was the most common soil unit, and the Soils 5 numbers were available for these soils. Textures were commonly given for the soil series. For some range sites, land types or general descriptions of soils were given in the soil taxonomic units. For example, sandy alluvial land was associated with the range site Sandy Bottomland in Area 3. These general descriptions were coded in the soil taxonomic unit variable in this data base.

Total Annual Production

Most range sites had total annual production given for favorable and unfavorable years. An average total production was estimated for this data base by averaging the favorable and unfavorable values reported in the guides.

Initial Stocking Rates

Initial stocking rates were given for most range sites by condition class. Rates were given as acres per animal unit per year-long grazing. These values were divided by 12 to obtain a monthly value, acres per AUM, and then were stored into this data base.

Utah

Utah had 84 Range Site Descriptions[19] identified by Region and MLRA. Utah did define a Utah Land Resource Unit code in the range site descriptions; but this was not coded into this data base. The 32 Woodland Ecosystems were not included in this data base.

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[17] *On file at SCS State Office: Range Conservationist, SCS Federal Building, Room 203, 200 4th Street S.W., Huron, S. Dak. 57350.*

[18] *On file at SCS State Office: Range Conservationist, SCS, 101 S. Main Street, Temple, Tex. 76501.*

[19] *On file at SCS State Office: Range Conservationist, SCS, 4012 Federal Building, 125 South State Street, Salt Lake City, Ut. 84147.*

Soils Information

The number of significant soils associated with each range site varied from 1 to 29. Soils series were the most common soil taxonomic unit; therefore, the Soils 5 numbers were available for nearly all of the range sites. Land types or general descriptions of soils occasionally were given as a significant soil (e.g., mixed alluvial land in range site Wet Meadows in MLRA 25). These general descriptions were coded in the soil taxonomic unit variable in this data base. No soils were reported for the Desert Bottoms range site, Semidesert Sand (juniper), Semidesert Shallow Hardpan, Upland Limy Loam (summer precipitation), Upland Shallow Hardpan (summer precipitation), Desert Shallow Loam, Semidesert Gravelly Loam (summer precipitation), Semidesert Sand (summer precipitation), Upland Stony Loam (summer precipitation), Upland Sand (summer precipitation), Upland Shallow Loam (summer precipitation), High Mountain Loam (summer precipitation), Upland Shale, Upland Stony Clay.

Total Annual Production

All range sites reported total annual production for favorable, unfavorable, and median years for an excellent condition site. Yields also were reported separately by condition class by favorable and unfavorable year. A range was given within each condition class for favorable and for unfavorable years. The number of plots upon which estimates of yield were made varied from 7 to 70, depending upon the range site. For excellent condition class, the upper limit of each climatic year was the estimate of total annual production first reported in the guide. Thus, the unfavorable year estimate is slightly higher than the estimated yields reported by condition classes. The initial estimates of yields were used in this data base.

Initial Stocking Rates

No initial stocking rates were given.

Washington

Washington had 25 Range Site Descriptions[20] identified by Region and MLRA. Precipitation was used to divide the state. Range sites were dated from 1981 to 1983. Woodland sites were not included in this data base.

Soils Information

All range sites have soils associated with them. The number of soil series or soil mapping units associated with each range site varied from 1 to 6. Texture and slopes were commonly associated with each soil. Soils 5 numbers were available for 95% of the soils.

Total Annual Production

All range site descriptions reported a total annual production for favorable and unfavorable years as well as the median years.

Initial Stocking Rates

All range site descriptions reported initial stocking rates by condition class. Stocking rates were based on 900 pounds of forage per AUM.

Wyoming

Wyoming had 250 Range Site Descriptions[21] identified by state land division zone, Region, and MLRA. The state land divisions were based on precipitation zones (table 7). Within the state land division, the Region and MLRA classifications were used to further subdivide the state. Both the precipitation and the state land division code were coded into the data base. Precipitation for the Mountains land division was reported as 20 inch plus. This was coded into the data base as 20 in the first precipitation columns (Card 3 col 1–2) and + in the second precipitation columns (Card 3 col 5–6). A common set of range site names was used across the precipitation zones. That is, the name Shallow Loamy was used within the 20 inch plus Mountains zone and the 15 to 19 inch Foothills and Mountains West zone; but the range site descriptions reflect the zone conditions.

Table 7.—Wyoming state land divisions.

Code	Topographic Precipitation Zone
A	20″ + Mountains
B	15″ - 19″ Foothills and Mountains West
C	10″ - 14″ Foothills and Basins West
D	7″ - 9″ Green River and Great Divide Basin
E	5″ - 9″ Big Horn and Wind River Basin
F	15″ - 19″ Foothills and Mountains East
G	10″ - 14″ Foothills and Foothills East
H	10″ - 14″ High Plains Southeast
I	15″ - 19″ Northern Plains
J	15″ - 19″ Foothills and Mountains Southeast
K	12″ - 14″ Southern Plains
L	15″ - 17″ Southern Plains
M	15″ - 17″ Northern Plains
N	10″ - 14″ Northern Plains
O	15″ - 19″ Blackhills
P	20″ - 24″ Blackhills (Woodland site)

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[20] *On file at SCS State Office: Range Conservationist, SCS, 360 U.S. Courthouse, West 920 Riverside Avenue, Spokane, Wash. 99201.*

[21] *On file at SCS State Office: Range Conservationist, SCS, Federal Building, Room 3124, 100 East "B" Street, Casper, Wyo. 82601.*

Soils Information

Soil taxonomic units reported for range sites varied by zones. Most range sites within zones 2, 5, 6, 7, 12, 13,and 14 had soils associated with the site. In zones 3 and 4, less than 50% of the sites had soils associated with them. In zones 1, 8, 9, 10, 11, and 16, no soils were reported for the range sites. If a soil taxonomic unit was reported, it usually was the soil series; therefore, the Soils 5 numbers were available.

Total Annual Production

All range site descriptions reported total annual production for favorable and unfavorable years as well as the median years. These production values are for range sites in excellent condition.

Initial Stocking Rates

All range site descriptions reported an initial stocking rate by condition class in acres per AUM.

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APPENDIXES
STRUCTURE OF COMPUTER FILES

Twenty individual state files contain range site description information. All files are stored on tape at the Fort Collins USDA Computer Center. The following job control language will allow read-only access to the tape, and copy 1 state file to disk space on the user's FCCC account. The control language could be modified to read more than one state file.

```
@ASG,T SCSRS*WEST-STATES., U9S, FS5966
@ASG,UP MYFILE,F///XXXX
@COPIN,S SCSRS*WEST-STATES.AZ,MYFILE
```

The tape is numbered FS5966. The maximum number of tracks required for a single state is 200. The default on the FCCC Univac is less than 200, so the user must specify the number of tracks using F///XXXX where XXXX is the number of tracks desired. To copy the entire tape onto disk would require 751 tracks. The state files are named SS where ss is the two letter state abbreviation. The order of the elements on the tape is as follows:

CA, CO, ID, MT, NV, NM, OR, UT, WA, WY, AR, FL, KS, LA, NE, ND, OK, SD, TX.

Each state file contains the range site-soils data in a four card standard format (Appendixes 1 and 2). This data set represents all range site descriptions as of 1984 for these 20 states. For this data set only, the sequence number identifies each range site-soil combination within each state. The number of range site-soil combinations within each state will exceed the number of range site descriptions because all MLRA-range site-soils combination were identified in order to link with other national level data bases. Data elements were described in the text under the Structure of Rangeland Data, and the individual state variations in the data were described within each state section.

Appendix 1.—Standard format for all range sites in RANGE FORAGE data base. For data definitions, see Appendix 2.

Card	Column	Contents
1	1–5	Sequence Number (numeric)
1	8–9	State Postal Code Abbreviation (alphanumeric)
1	12	Region (alphanumeric)
1	15–18	Major Land Resource Area (alphanumeric) (except Montana: Montana Land Resource Division, alpha)
1	21–24	New Mexico subresource area (alphanumeric) or Texas Area Code (numeric)
1	27–78	Range Site Name (alphanumeric)
2	1–6	Soils 5 Number (alphanumeric)
2	12–78	Soil Taxonomic Unit (alpha)
3	1–2	Precipitation zone: low (inches)
3	5–6	Precipitation zone: high (inches)
3	9–11	Texture modifiers (alpha)
3	14–17	Texture (alpha)
3	20–21	Slope: low (percent)
3	24–25	Slope: high (percent)
3	28–58	Phase/Class descriptions (alpha)
3	60–64	Total annual production: favorable year (lb/ac)
3	67–70	Total annual production: unfavorable year (lb/ac)
3	72–76	Total annual production: median year (lb/ac)
4	1–6	Initial stocking rate: excellent condition, low estimate. Units of acre/AUM.
4	8–13	Initial stocking rate: excellent condition, high estimate. Units of acres/AUM.
4	15–20	Initial stocking rate: good condition, low estimate. Units of acres/AUM.
4	22–27	Initial stocking rate: good condition, high estimate. Units of acres/AUM.
4	29–34	Initial stocking rate: fair condition, low estimate. Units of acres/AUM.
4	36–41	Initial stocking rate: fair condition, high estimate. Units of acres/AUM.
4	43–48	Initial stocking rate: poor condition, low estimate. Units of acres/AUM.
4	50–55	Initial stocking rate: poor condition, high estimate. Units of acres/AUM.
4	57–76	Plant communities in Idaho (alpha) or PE zones in Texas (alphanumeric).
4	73	Land divisions code for Nebraska (numeric), North Dakota (numeric), Wyoming (alpha).

Appendix 2.—Data dictionary for RANGE FORAGE data base.

Annual production — see Total Annual Production

Initial Stocking Rates — Initial stocking rates for domestic livestock grazing use are given for each range site in each of the four condition classes: poor, fair, good, excellent. See table 2 for a listing of the states which provided this information.

Land Division Codes — These codes describe divisions of a state unique to that state. Land Division Codes for Nebraska are given in table 5, for Montana in table 4, for North Dakota in table 6, and for Wyoming in table 7.

Major Land Resource Area (MLRA) — Land classification from USDA SCS 1981.

PE — see Potential Evapotranspiration

Phase/Class Description — Phase/class descriptions of soils were included in this data base if the phase or class description was used to further define the soil associated with the range site. Standard abbreviations for Phase/class descriptions from the SCS National Soils Handbook are given in Appendixes 2 and 3. If no abbreviation existed, the phase/class description was recorded in full.

Plant Communities — Plant communities descriptions were given for the range sites in Idaho. The description consists of the dominant species (up to three) abbreviated with the four letter code (first 2 letters of genus and species).

Potential Evapotranspiration Zones (PE) — Potential Evaporation Zones were used to further divide Texas. These were coded into a category in the data base. Other states, such as California, also reported potential evapotranspiration but not for all range sites. Hence, these states did have a separate category for PE. Refer to the state description to determine if PE was coded.

Precipitation Zone — If precipitation was given in the range site name, or state land division code, it was coded in the data base.

Range Site Name — Name given in the Range Site Description

Region — Land cover classification as defined by USDA SCS 1981

Sequence Number — Sequence number associated with each range site within a state.

Soils 5 Number — Unique number associated with soil series in the SCS data base called Soils Interpretation Record.

Soil Taxonomic Unit — Soil taxonomic unit used in the range site description to describe representative soils associated with the range site. Could be order, family, series.

State Code — United States Postal Code as defined in the SCS National Range Handbook.

Stocking Rate — see Initial Stocking Rate

Texture — Soil description used to further refine the soil associated with the range site. Standard abbreviations from the National Range Handbook, also given in Appendixes 2, 3, and 5.

Texture modifiers — Soil description used to further refine the soils associated with the range site. Standard abbreviations given in the National Range Handbook, and Appendix 3 of this report.

Total Annual Production — Total annual production air-dry in units of pounds per acre. Table 2 defines the states which provided this information. Values given in this data base for favorable, median, and unfavorable years.

Appendix 3.—Abbreviations for texture, texture, phase/class descriptions taken from National Soils Handbooks.

Texture modifier	
BY	Bouldery
BYV	Very bouldery
BYX	Extremely bouldery
CB	Cobbly
CBA	Angular cobbly
CBV	Very cobbly
CBX	Extremely cobbly
CN	Channery
CNX	Extremely channery
CR	Cherty
CRC	Coarse cherty
CRV	Very cherty
CRX	Extremely cherty
FL	Flaggy
FLX	Extremely flaggy
FLV	Very Flaggy
GR	Gravelly
GRC	Coarse gravelly
GRF	Fine gravelly
GRV	Very gravelly
GRX	Extremely gravelly
MK	Mucky
PT	Peaty
RB	Rubbly
SH	Shaly
SHV	Very shaly
SHX	Extremely shaly
SR	Stratified
ST	Stony
STV	Very stony
STX	Extremely stony
SY	Slaty
SYV	Very slaty
SYX	Extremely slaty

Texture terms	
COS	Coarse sand
S	Sand
FS	Fine sand
VFS	Very fine sand
LCOS	Loamy coarse sand
LS	Loamy sand
LFS	Loamy fine sand
LVFS	Loamy very fine sand
COSL	Coarse sandy loam
SL	Sandy loam
FSL	Fine sandy loam
VFSL	Very fine sandy loam
L	Loam
SIL	Silt loam
SI	Silt
SCL	Sandy clay loam
CL	Clay loam
SICI	Silty clay loam
SC	Sandy clay
SIC	Silty clay
C	Clay
COL*	Coarse Loam
VCOL*	Very Coarse Loam
CO*	Coarse
Terms used in lieu of texture:	
CB	Coprogenous earth
CEM	Cemented
CIND	Cinders
DE	Diotomaceous earth
FB	Fibric material
GRAVEL	Gravel
GYP	Gypsiferous material
HM	Hemic material
ICE	Ice or frozen soil
IND	Indurated
MARL	Marl
MPT	Mucky-peat
MUCK	Muck
PEAT	Peat
SG	Sand and gravel
SP	Sapric material
UWB	Unweathered bedrock
VAR	Variable
WB	Weathered bedrock

**Abbreviations added for this data set, not standard.*

Appendix 4.—Standard abbreviations for phase/class descriptions as defined in the National Soils Handbook.

AFFR - Annual Frost-free rainfall
ALKALI
ALL
BRIEF
CALC SURF - Calcareous surface
COASTAL
CHANNELED
COLD
COMMON - common flooding
COOL
DEPTH
DISSECTED
DRAINED
DRY
ELEV - elevation
ERODED
ETA - Evapotranspiration, actual
FFS - Frost-free
FREQ - Frequent flooding
GULLIED
HIGH ELEV - High elevation
HIGH PE - High potential evapotranspiration
HIGH PPT - High precipitation
HUMMOCKY
IRR - Irrigated
LONG
LOW ELEV - Low elevation
LONG FFS - Long frost-free season
LOW PE - Low potential evapotranspiration
LOW PPT - Low precipitation
MAAT - Mean annual air temperature
MAP - Mean annual precipitation
MAST - Mean annual soil temperature
MED PE - Medium potential evapotranspiration
MED PPT - Medium precipitation
MOD ALKALI - Moderately alkali
MOD DEEP - Moderately deep
MOD SAL-ALK - Moderate saline-alkali
MOD SALINE - Moderately saline
MOD TEMP - Moderate temperature
MOD THICK
MOD WELL DR - Moderately well
MOIST
NIRR - Nonirrigated
NONCALC SURF - Noncalcareous surface
NONE - No flooding
NONERODED
NONSALINE
NORTH - North or east aspect
OCCAS - Occasional flooding
OVERWASH
PARTIALLY DR - Partially drained
PE - Precipitation effictivity
PONDED
POORLY DR - Poorly drained
RANGELAND
RARE - Rare flooding
ROCKY
SALINE
SAL-ALK - Saline-alkali
SER ER - Severely eroded
SHALLOW
SHORT FFS - Short frost-free season
SLI ALKALI - Slight alkali
SLI SALINE - Slightly saline
SLI SAL-ALK - Slightly saline alkali
SMD - Soil moisture deficit
SOUTH - South or west aspect
STR ALKALI - Strongly alkali
STR SALINE - Strongly saline
STR SAL-ALK - Strongly saline-alkali
SUBIRR - Subirrigated
SW POORLY DR - Somewhat poorly drained
THICK SURF - Thick surface
THICK - Thick solum
THIN SURF drained
UNDRAINED
UNDULATING
WARM
WELL DR - Well drained surface
WET
WINTER PPT - Winter precipitation
WOODLAND
V BRIEF - Very brief
V COLD - Very cold
V LONG - Very long
V POORLY DR - Very poorly drained
V ROCKY - Very rocky
V SHALLOW - Very shallow

Joyce, Linda A., David E. Chalk, Andrew D. Vigil. Range forage data base for 20 Great Plains, southern and western states. USDA Forest Service General Technical Report RM-133, 17 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

This paper documents the development and structure of the RANGE FORAGE data base, a subset of information from all Soil Conservation Service Range Site Descriptions for 20 states: Arkansas, Arizona, California, Colorado, Florida, Idaho, Louisiana, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, Wyoming. Information in the data set includes range site name, location identifiers, total annual production, soils information, and initial stocking level rates.

Keywords: Range site, forage production, western United States, stocking level, data base

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Rocky
Mountains

Southwest

Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

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United States
Department of
Agriculture

Forest Service

Rocky Mountain
Forest and Range
Experiment Station

Fort Collins,
Colorado 80526

General Technical
Report RM-134

Engelmann Spruce Seed Production and Dispersal, and Seedling Establishment in the Central Rocky Mountains

Robert R.

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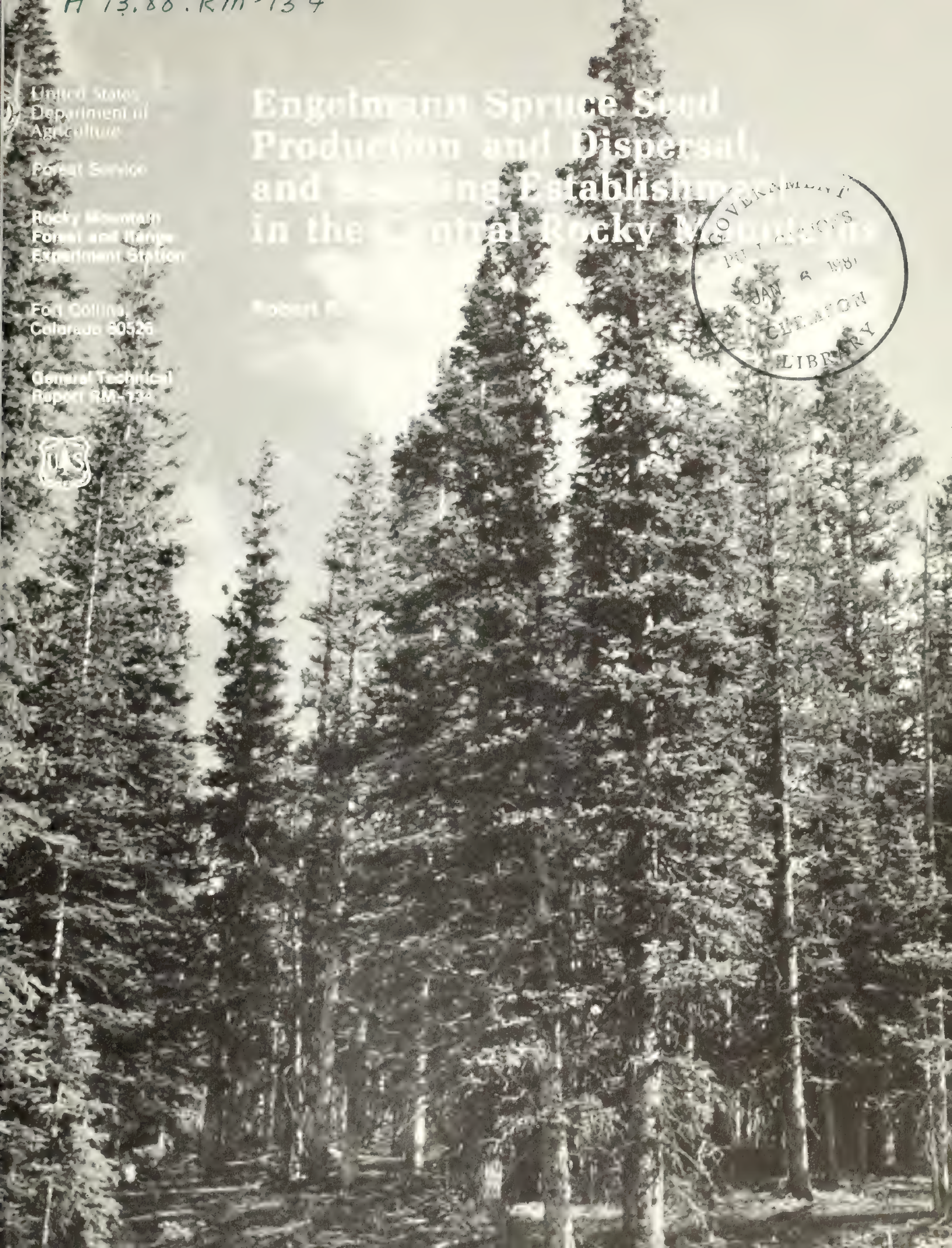

Abstract

Engelmann spruce seed production and dispersal, and seedling establishment in the central Rocky Mountains indicate that in the *Abies lasiocarpa/Vaccinium scoparium* habitat type, shaded, mechanically scarified, mineral soil seedbeds on north aspects can be adequately restocked naturally within a 5-year period in clearcut openings 300 to 450 feet wide. With shade or scarification alone, size of opening that will restock is reduced to 200 to 350 feet. The effective seeding distance is so limited on unshaded natural seedbeds on north aspects and on south aspects regardless of the seedbed conditions that the expectation of natural restocking in a reasonable period of time with clearcutting, is not a realistic option.

Cover Photo.—Old-growth Engelmann spruce-subalpine fir, Fraser Experimental Forest, Colorado.

USDA Forest Service
General Technical Report RM-134

September 1986

Engelmann Spruce Seed Production and Dispersal, and Seedling Establishment in the Central Rocky Mountains

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Rocky Mountain Forest and Range Experiment Station[1]

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Engelmann Spruce Seed Production and Dispersal, and Seedling Establishment in the Central Rocky Mountains

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Prompt establishment of Engelmann spruce (*Picea engelmannii* Parry ex. Engel.) natural reproduction following clearcutting is a major objective in the management of spruce-subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) forests in the central Rocky Mountains (Alexander 1974, 1977). Engelmann spruce is the most valuable timber species of the type and research and management efforts are directed toward perpetuating it. However, subalpine fir and occasionally lodgepole pine (*Pinus contorta* Dougl. ex Loud.) are present in spruce-fir stands and contribute to overall stocking.

Knowledge is lacking of (1) the frequency of good seed crops and the kinds of stands or trees that produce good spruce crops in the uncut stands around the perimeter of openings; (2) the distance viable seeds are dispersed from the seed source into openings; and (3) the number of sound seeds required for an acceptable level of stocking in relation to seedbed, environmental, biotic, and management factors. This information is essential if proper decisions are to be made concerning the size of opening that will restock naturally, kind and amount of seedbed preparation, and whether to plant instead of depending on natural regeneration or to require the use of partial cutting methods that provide a seed source on site.

Past studies of Engelmann spruce seedfall in the Rocky Mountains indicate that intervals between good to bumper seed production years are erratic, with more poor than good seed crops (Alexander 1969, 1974; Jones 1967; Noble and Ronco 1978). The pattern of seed dispersal into clearcut openings observed in the Rocky Mountains is strongly influenced by the direction of prevailing winds. Sound seedfall generally decreases rapidly from within the stand to the stand edge, and beyond into the clearcut opening. In these studies, about 50% of the amount of seed falling under uncut stands was dispersed as far as 100 feet into the opening from the windward stand edge, and about l0% dispersed as far as 300 feet. The initial rapid decrease in seedfall was followed by a gradual tailing-off, but in the openings observed (200 to 800 feet wide), a U-shaped pattern of seedfall was poorly defined. Minimum seedfall—less than 5% of the seed falling under uncut stands—usually occurred about two-thirds of the way (150 to 600 feet) across the openings from the windward stand. Seedfall then increased, but at the leeward stand edge it was only about 30% of the sound seedfall along the windward edge (Alexander 1969, Noble and Ronco 1978, Roe 1967, Roe et al. 1970).

Past research and observations of spruce germination and survival in the Rocky Mountains have most often been concerned with identifying the environmental factors limiting success (Alexander 1984, Noble and Alexander 1977). Relatively little effort has been directed toward determining the supply of Engelmann spruce seed required for an acceptable level of stocking for a particular set of site conditions. Seed:seedling ratios previously determined for spruce have been averages over a wide range of site conditions (Noble and Ronco 1978).

STUDY AREAS

Seed production data were collected from 1970 through 1984 from thirteen sample plots, 132 feet on a side, established in old-growth spruce-fir forests, on the Fraser Experimental Forest in Colorado (Alexander et al. 1986). Plots covered a range of elevations, slopes, aspects, ages of dominant trees, and site productivity (Alexander et al. 1986). Stand characteristics for each location are shown in table 1.

Seed dispersal data were collected on two areas on the Fraser Experimental Forest from 1956 through 1965, and on five areas on different national forests in Colorado from 1962 through 1971 (Alexander 1969, Alexander and Edminster 1983, Noble and Ronco 1978). Seed sources were typical, old-growth spruce-fir stands bordering the windward and leeward edges of clearcut openings 200 to 800 feet wide, oriented with their long axis at right angles to the prevailing winds. Spruces generally accounted for between 70% and 90% of the basal area of the seed source.

Field observations of seedling establishment ratios were made from 1968 through 1982, on the Fraser Experimental Forest, on two plots approximately 4.5 miles apart (Alexander 1983, 1984). One is on a north and the other is on a south aspect at about 10,500 feet elevation. Both plots are enclosed within 100- x 110-foot hardware-cloth rodent exclosures (Noble and Alexander 1975) in the center of 3.5 acre clearcut openings in spruce-fir stands. The hardware cloth generally excluded deer mice (*Peromyscus maniculatus* Wagner), red-backed voles (*Clethrionomys gapperi* Vigors), mountain voles (*Microtus montanus* Peale), western chipmunks (*Eutamias minimus* Bachman), and pine squirrels (*Tamiasciurus hudsonicus fremonti* Audubon and Bachman), but not pocket gophers (*Thomomys talpoides* Richardson) or birds that feed on tree seeds, such as the gray-headed (dark-eyed) junco (*Junco caniceps* Woodhouse) (Noble and Shepperd 1973).

The habitat type on the Fraser Experimental Forest and on two of the national forests is *Abies lasiocarpa/Vaccinium scoparium*, the most common spruce-fir habitat

Table 1.—Average stand characteristics for dominant and codominant Engelmann spruce and total trees, seed production study, Fraser Experimental Forest.

Plot number	Trees		Basal area		Diameter		Height		Live crown	
	Spruce	Total	Spruce	Total	Spruce	Total	Spruce	Total	Spruce	Total
	Number per acre		Square feet per acre		---- Inches ----		----- Feet -----		---- Percent ----	
1	64	319	84	150	15.6	9.4	79	50	74	68
2	54	249	102	176	19.2	11.8	90	58	67	66
3	88	220	139	196	17.4	12.9	62	47	72	70
4	100	320	195	306	19.1	13.4	81	59	64	61
5	95	525	94	258	13.7	9.6	68	50	62	54
6	63	345	104	197	17.5	10.3	87	55	64	60
7	65	365	107	205	17.4	10.1	88	52	71	65
8	58	286	116	193	19.3	12.0	95	59	63	62
9	90	278	105	183	14.8	10.9	85	63	55	55
10	43	283	61	145	16.6	10.1	87	54	66	65
11	35	213	72	141	19.9	11.2	100	56	74	70
12	63	293	80	182	15.6	10.8	81	57	71	67
13	74	205	150	206	19.7	13.8	99	68	66	65

type in Colorado (Hess and Alexander 1986). The *Vaccinium* union does not compete as severely with tree seedlings as do some other habitat types. The habitat types on the other three national forests were not described but understory vegetation was dominated by *Mertensia*, or *Carex* and other graminoids.

METHODS

Seed Production

Seed production was estimated from seeds collected in 10 1-square-foot seed traps randomly located within each 0.4-acre plot (fig. 1). Seed trap contents were collected one or more times each fall beginning in mid- to late September, weather conditions permitting, and again the following spring. All seeds were tested for soundness and recorded as (1) filled, or (2) partially filled or empty. Estimates of total quantities of seed produced were based on counts of filled seed only.

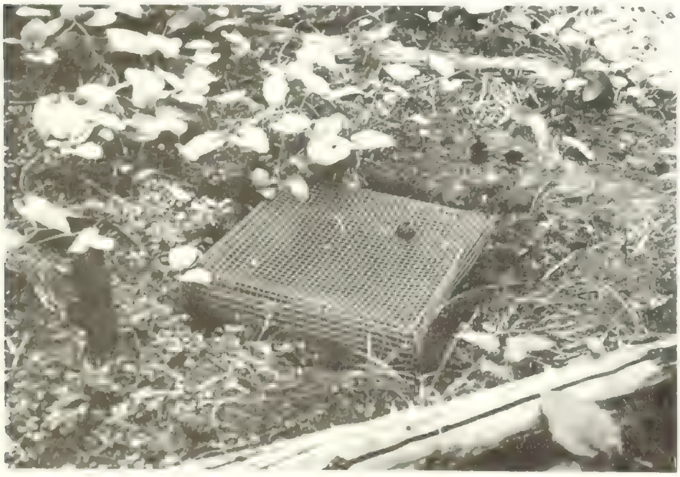

Figure 1.—One-foot-square wire seed trap in place, Fraser Experimental Forest.

Differences in seedfall for locations and years were tested by analysis of variance, with a square root transformation ($\sqrt{X + 3/8}$) of the number of filled seeds per trap as the dependent variable. Data were transformed to provide homogeneous variances.

The following subjective categories, described by Alexander and Noble (1976), were used to rate the seed crops.

Filled seeds per acre	**Seed crop rating**
<10,000	Failure
10,000–50,000	Poor
50,000–100,000	Fair
100,000–250,000	Good
250,000–500,000	Heavy
>500,000	Bumper

The relationship between the amount of filled seed produced and total seedfall was tested by regression analysis, with the number of filled seeds per trap as the dependent variable.

Standard stand inventory data were collected on each plot (Alexander et al. 1986). These were used to compute the usual stand, tree, and crown parameters as a basis for relating seed production to some measure of stand density, and/or crown and tree characteristics. Parameters were calculated using only dominant and codominant spruces, because numerous studies have shown that coniferous species of these crown classes produce three-fourths or more of the seedfall (Fowells and Schubert 1956, Franklin et al. 1974). A stepwise regression program was then used to select the set of independent variables best correlated with seed production.

Seed Dispersal

Seed count data were obtained from seed traps placed on transect lines. On two, 400-foot wide, clearcut areas, on the Fraser Experimental Forest, 15 3.3-square-foot (0.25 mil-acre) seed traps were placed along each of two parallel transect lines, about 132 feet apart, at right angles to the windward stand edge. Seed traps on each transect line were placed at 33-foot intervals, beginning 33 feet into the uncut stand along the windward stand edge and ending 33 feet into the leeward stand edge.

In the other five clearcut areas, 1-foot-square seed traps were placed on transect lines that were parallel to the long axis of the clearing. Ten seed traps were placed on each transect line, at 33-foot intervals. Transect lines were 66 feet apart, with the outer two transect lines 33 feet from the windward and leeward stand edges. One additional transect line was placed 66 feet inside both the uncut windward and leeward stands.

Seed trap contents were collected annually. Sound seed counts (based on cutting tests) were tabulated by trap on each area for each year of observation.

The relationship between mean seedfall and distance from source was explored by plotting the number of sound seeds falling from the windward stand edge into the opening (for a distance as far as seedfall appeared to be uninfluenced by the leeward stand) against the number of sound seeds falling under the uncut windward stand, which was the source of most of the seedfall in the openings. A nonlinear least squares regression program was then used to fit the data to an exponential model.

Seedling Establishment

Four seedbed treatments were tested in a two- by two-factorial, replicated over 10 years time, in randomized blocks. A set of twelve 0.25 mil-acre seedbeds (four seedbed treatments, replicated three times) were prepared on each aspect, each year from 1968 through 1977. The four seedbed treatments were (1) scarified-shaded, (2) scarified-unshaded, (3) unscarified-shaded, and (4) unscarified-unshaded (Alexander 1983, 1984; Noble and Alexander 1977). Plots were scarified by hand to remove all organic material to mineral soil. Scarification simulated scalping with a dozer blade. Wooden frames made from 2-inch wide furring strips with alternate 2-inch spaces, elevated 8 to 10 inches above the ground on metal framing, provided overhead shade (fig. 2). Slats of the shade frames were oriented in a north-south direction to provide alternate periods of shade and sunlight.

The Engelmann spruce seed used in this study was collected locally. New collections were made only when stored seed viability dropped to less than 60%. In late September of each year (1968 to 1977), an estimated 125 viable seeds were evenly broadcast on each seedbed. The total number of seeds sown per seedbed each year varied from 165 to 210, depending on viability determined from laboratory germination tests. The seeds were not covered, because the intent was to simulate natural regeneration. The number of seeds sown corresponds to 500,000 sound seeds per acre, which can be expected from a heavy natural seedfall. Plots were located at least 150 feet from the nearest timber edge to minimize the input of seed from adjacent timber stands. However, the seed: seedling ratios calculated should be considered minimums, especially because they are extrapolated from a heavy seedfall production.

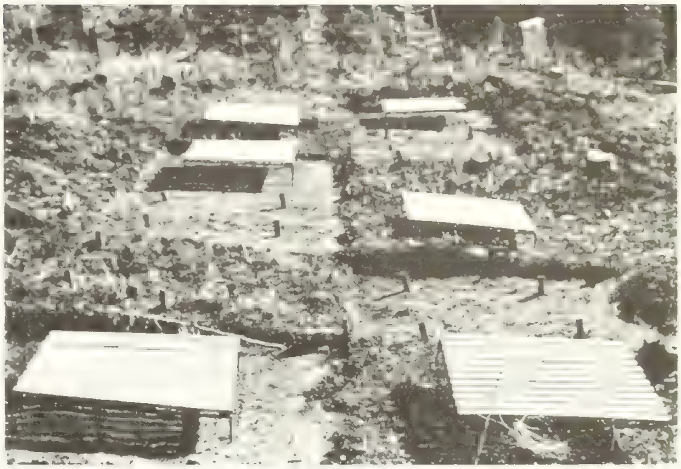

Figure 2.—Shade frame in place on a scarified-shaded seedbed, Fraser Experimental Forest.

During the first growing season after each sowing, germination, survival, and mortality were recorded at least twice weekly; after the first growing season, counts were made weekly. Measurements were begun in mid-June, when the plots were first clear of snow, and ended about mid-October, with the onset of winter snow cover.

RESULTS AND DISCUSSION

Seed Production

Seed was produced in larger quantities and at more frequent intervals than previously measured on the Fraser Experimental Forest (Alexander 1969) and elsewhere in the central Rocky Mountains (Alexander 1974, Noble and Ronco 1978), as values below, averaged over all Fraser locations, show:

Year	Number of sound seeds per acre in thousands
1970	342
1971	208
1972	281
1973	19
1974	271
1975	193
1976	15
1977	1,114
1978	96
1979	13
1980	682
1981	34
1982	8
1983	82
1984	8

Based on this average seed production, crops were rated as shown for the 15 years of record.

Seed crop rating	Number of years
Failure	2
Poor	4
Fair	2
Good	2
Heavy	3
Bumper	2

There were differences in the quantity of seed produced from year to year. During the first 5 years of observation, good to heavy seed crops were produced in 4 out of 5 years. During the second 5 years, good to bumper crops were produced in 2 years; but in the last 5 years, good to bumper crops were produced in only 1 year (fig. 3). Seed crops also varied considerably between locations. Not all locations produced good to bumper crops every good seed year, and some locations produced bumper crops in 3 or more years. Analysis of variance of the seed count data revealed that differences between years, locations, and the years-times-locations interaction were all highly significant ($p \leqslant 0.01$).

The amount of filled seed for each year at each location was related significantly to the annual total seedfall, as shown in the following equation:

$$Y = 0.499\ X \qquad [1]$$

$R^2 = 0.87$, $S_{y \cdot x} = 157{,}000$ (coefficient of determination not centered about the mean—zero-intercept model)

where

Y = number of filled seeds per acre per year, and
X = number of total seeds per acre per year.

The equation, which accounts for 87% of total variation in sound seed production, shows that the number of filled seed produced increases linearly with total seedfall. The large standard error of estimate also indicates considerable variability in the relationship between filled and total seed production between years and locations.

Another significant finding in this study is that despite good or better seed production in 7 years, an average of only 46% (range 26% to 68%) of the total seedfall collected were filled in those years. Seed loss to insects, in particular to the spruce seed worm (*Cydia youngana*), accounted for a large portion of the unsound, partially filled seeds (Schmid et al. 1981).

Regression analyses of seed production and stand inventory variables resulted in the following equations:

$$Y = 5{,}395\ X^{0.796} \qquad [2]$$

$$S_{y \cdot x} = 87{,}600$$

where

Y = periodic average annual sound spruce seed production per acre, and
X = basal area of dominant and codominant spruces per acre.

$$Y = 5{,}936\ (X_1\ X_2)^{1.217} \qquad [3]$$

$$S_{y \cdot x} = 84{,}000$$

where

Y = periodic average annual sound spruce seed production per acre,
X_1 = average height of dominant and codominant spruces, and
X_2 = average number of stems of dominant and codominant spruces per acre.

The relationships of seed production to stand variables in both equations are weak (only 30% to 40% of the variation is accounted for), but no improvement was possible using other combinations of stand variables. However, the standard errors of estimate appear reasonable for this kind of data.

The average annual seed production was used as the dependent variable, because it is difficult to account for annual variation. Furthermore, the independent variables did not change significantly from year to year.

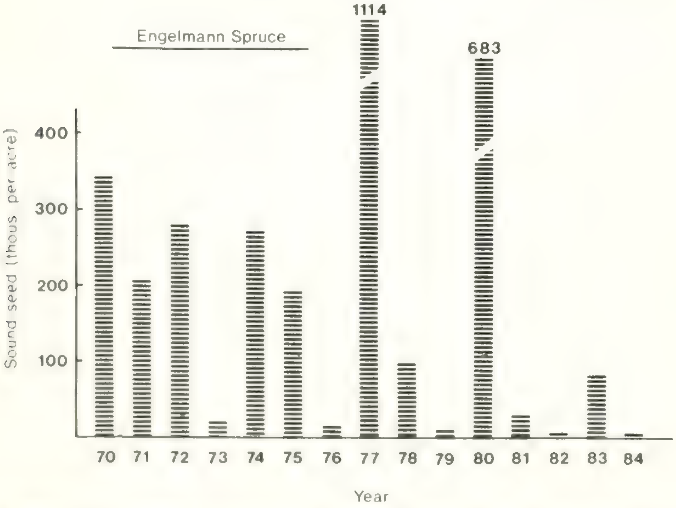

Figure 3.—Average Engelmann spruce sound seed production in relation to years.

Seed Dispersal

The following equation was used to fit the seed dispersal data by a nonlinear least squares regression program.

$$SD = SO \exp[-b_1(D + 33)b^2] \qquad [4]$$

where

SD = Number of sound seeds per acre falling at distance D into the openings (the windward stand edge is denoted by $D = 0$),
SO = number of sound seeds per ha falling under the uncut stand 33 feet from the windward stand edge (denoted by ($D = -33$),
D = distance in feet into the opening from windward stand edge, and
b_1, b_2 = partial coefficients of SO and D, respectively.

The estimated value of b_2 was nearly 1.0; therefore, the following simplified model was then fit:

$$SD = SO \exp[-b_1(D + 33)]. \qquad [5]$$

The residual sums of squares of the two models were nearly equal. The resulting equation from the single coefficient model is:

$$SD = SO \exp(-0.00735D - 0.243) \qquad [6]$$

$R^2 = 0.99$, $Sy{:}x = 37{,}500$ sound seeds per acre.

Although the equation accounts for 99% of the variability centered about the mean, the high standard error of estimate indicates that a large amount of variability is not accounted for by the equation.

The precision of equation [6] is about the best that can be expected for estimating seedfall in relation to seed production and distance from source because of the variation in seedfall from year to year and from place to place. More data are not likely to reduce the large standard error of estimate (Alexander and Edminster 1983).

Equation [6] is useful in estimating potential Engelmann spruce seedfall into openings in the central Rocky Mountains. Figure 4 was developed from equation [6] to estimate seedfall into openings for distances up to 600 feet from the windward stand edge. Seed production under uncut stands was set at a range of 50,000 to 1,000,000 sound seeds per acre.

Estimates of seedfall into openings generally follow the pattern previously described for the Rocky Mountains. The amount of seedfall dispersed to the windward stand edge is about 80% of the seedfall under the uncut stand. About 40% of the amount of seedfall under the uncut windward stand is dispersed as far as 100 feet, and about 10% as far as 300 feet. The rapid decline in seedfall then levels off, with about 1% of the amount of seed falling under uncut stands dispersed as far as 600 feet from the windward stand edge. This is in general agreement with the 0.5% to 5% estimates of seedfall at 600 feet from source observed by Roe (1967). There are two important differences, however: equation [6] is based on estimates of sound seed, not total seedfall, and on two 10-year periods of observation.

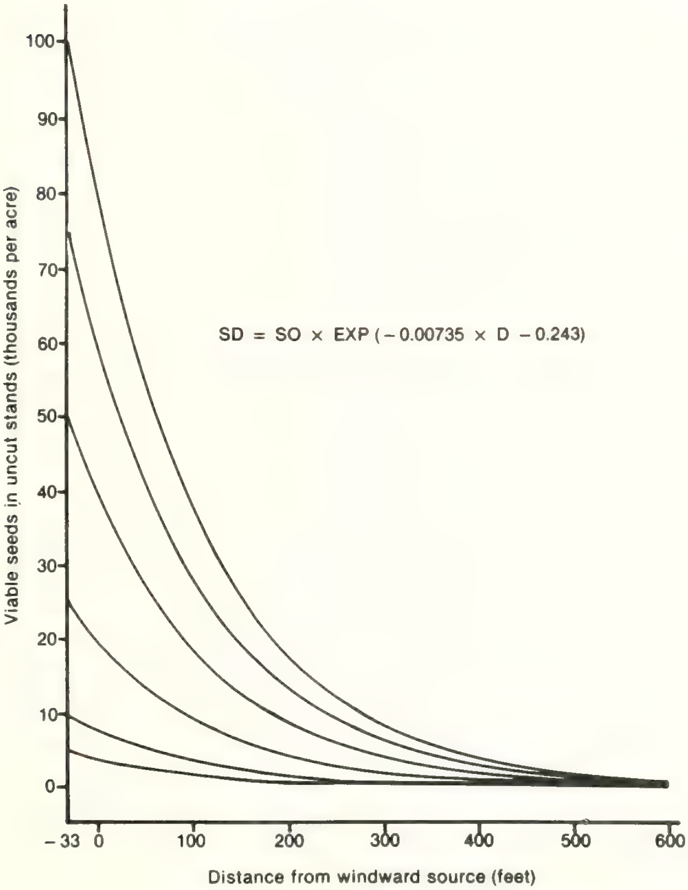

Figure 4.—Seed dispersal in relation to seed production in uncut stands and distance from source (estimated from equation [6]).

Seedling Establishment

Germination

Germination was considerably better on the north aspect than on the south aspect (table 2). However, total germination on the north aspect for all years was only 6.1%, ranging from a high of 10.5% in 1974 to a low of 0.9% in 1971 (table 2). Germination was improved significantly in most years by scarification but not by shade. The scarification x years interaction was highly significant, indicating that there was considerable variability in germination from year to year on scarified seedbeds (Alexander 1984).

Total germination for all years on the south aspect was only 2.9%, ranging from a high of 14.5% in 1972 to a low of 0.2% in 1970 (table 2). In some years, shade significantly improved germination, and in a few years, the combination of shade and scarification significantly improved germination. All interactions between years and cultural treatments were highly significant, indicating high variability in germination among the treatments from year to year (Alexander 1984).

Survival

Survival also was better on the north aspect than on the south aspect (table 2). However, total survival on the north aspect at the end of the study was only 1.4% of the viable seeds sown. Seedlings that survived through the fifth growing season generally survived to the end of the study. In most years, survival was significantly improved by scarification, by shade, and by the combination of scarification and shade. The scarification x years interaction and the differences in survival between years also were significant (Alexander 1984).

On the south aspect, total survival was only 0.2% of the viable seeds sown (table 2). Although seedlings that survived through the fifth growing season generally survived to the end of the study, there was no survival on any of the seedbed treatments for seeds sown after 1975. In those few years when seedlings survived beyond the first year, shade and the combination of shade and scarification significantly improved survival. The shade x years interaction was significant, indicating high variability between years (Alexander 1984).

Mortality

Seventy-six percent of the seedlings that germinated on the north aspect died by the end of the study. About two-thirds of the total mortality occurred the first year (table 3). On the south aspect, 95% of the seedlings were

Table 2.—Percent germination and survival of Engelmann spruce by aspect, seedbed treatment, and year (basis number of viable seeds sown) (Alexander 1984).

Year	Scarified and shaded				Scarified and shaded				Unscarified and shaded				Unscarified and unshaded				Total			
	Germination	Survival end of 1st	5th	study[1]	Germination	Survival end of 1st	5th	study[1]	Germination	Survival end of 1st	5th	study[1]	Germination	Survival end of 1st	5th	study[1]	Germination	Survival end of 1st	5th	study[1]
North aspect																				
1969	21.1	10.9	7.5	6.9	12.8	7.2	3.2	3.2	4.5	1.6	1.3	0.8	0.8	0	0	0	9.8	4.9	3.0	2.7
1970	12.5	8.8	4.5	4.3	7.2	4.3	1.6	1.6	4.5	2.1	0.3	0.3	1.3	0.5	0.5	0.5	6.4	3.9	1.8	1.7
1971	1.1	0.5	0.5	0.5	2.1	2.1	0.5	0.5	0	0	0	0	0.5	0.3	0	0	0.9	0.7	0.3	0.3
1972	6.9	1.3	0.8	0.8	11.2	0.8	0	0	1.6	0.3	0	0	2.4	0.3	0	0	5.5	0.7	0.2	0.2
1973	7.2	4.0	2.1	2.1	3.5	1.3	0.3	0.3	9.6	5.9	3.5	2.9	3.2	1.9	0	0	5.9	3.3	1.5	1.3
1974	8.0	5.9	2.9	2.7	2.1	1.1	0.3	0.3	21.1	4.5	2.4	2.1	10.9	2.1	0.5	0.5	10.5	3.4	1.5	1.4
1975	9.3	3.7	0.5	0.5	8.3	3.7	0.5	0.5	4.8	2.9	1.6	1.3	1.1	0.5	0	0	5.9	2.7	0.7	0.6
1976	1.6	0.5	0.3	0.3	1.1	0.5	0.3	0.3	8.3	5.9	2.9	2.9	2.1	1.9	1.3	1.3	3.3	2.1	1.2	1.2
1977	10.7	8.3	2.4	2.4	4.8	2.4	0.3	0.3	1.3	1.1	0.3	0.3	1.1	0.5	0	0	4.5	3.1	0.7	0.7
1978	15.2	10.9	9.9	9.9	11.7	7.2	6.1	6.1	4.5	2.9	1.6	1.6	0.3	0	0	0	7.9	5.3	4.4	4.4
Aver.	9.4	5.5	3.1	3.0	6.5	3.1	1.3	1.3	6.0	2.7	1.4	1.2	2.4	0.8	0.2	0.2	6.1	3.0	1.5	1.4
South aspect																				
1969	6.7	1.3	0.3	0.3	2.1	0	0	0	6.9	2.4	1.9	1.9	2.4	0	0	0	4.5	0.9	0.5	0.5
1970	0	0	0	0	0	0	0	0	0.8	0.3	0.3	0.3	0	0	0	0	0.2	0.1	0.1	0.1
1971	1.6	0.5	0.5	0.5	1.3	0	0	0	0.3	0	0	0	0.5	0	0	0	0.9	0.1	0.1	0.1
1972	10.9	1.9	0.8	0.8	9.6	0.5	0	0	26.9	1.1	0	0	10.7	0	0	0	14.5	0.9	0.2	0.2
1973	5.9	2.4	1.3	1.3	0	0	0	0	5.9	2.4	1.1	0.5	2.7	1.3	0	0	3.6	1.5	0.6	0.5
1974	0	0	0	0	0	0	0	0	5.6	0.3	0	0	5.1	0	0	0	2.7	0.1	0	0
1975	0.3	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0.3	0	0	0
1976	0.3	0	0	0	0	0	0	0	0.8	0.3	0	0	0	0	0	0	0.3	0.1	0	0
1977	2.7	0.3	0	0	0	0	0	0	4.3	0.3	0	0	0	0	0	0	1.7	0.1	0	0
1978	0.5	0	0	0	0.5	0	0	0	0.5	0	0	0	0	0	0	0	0.4	0	0	0
Aver.	2.9	0.6	0.3	0.3[2]	1.4	0.1	0	0	5.3	0.7	0.3	0.3	2.1	0.1	0	0	2.9	0.4	0.2	0.2

[1] *Seedling age in 1982 ranged from 5 years old (1978 germination) to 14 years old (1969 germination).*

[2] *Seedling age in 1982 ranged from 10 years old (1973 germination) to 14 years old (1969 germination).*

dead by the end of the study, with more than 90% of the total mortality occurring the first year (Alexander 1984).

Drought was the most significant cause of mortality on both aspects, followed by clipping by birds (table 4). On the north aspect, these two factors plus frost heave and snowmold accounted for nearly 90% of the mortality. On the south aspect, drought, clipping, and heat girdle accounted for about 90% of the mortality (Alexander 1984).

Seed:Seedling Ratios

The lowest seed:seedling ratios were on the scarified-shaded seedbeds, on the north aspect, where treatment was most effective in conserving moisture by lowering temperatures of both soil and seedlings, and reducing competing vegetation (Alexander 1983).

Neither shade nor scarification was as effective in conserving moisture as the combination of shade and scarification on the north aspect; fewer seeds germinated and fewer seedlings survived on the scarified-unshaded and unscarified-shaded seedbeds. Survival stabilized on all treated seedbeds by the fifth growing season, but it required nearly 2.5 times as many seeds to produce a 5-year-old seedling on the scarified-unshaded and unscarified-shaded seedbeds as on the scarified-shaded seedbeds. The highest seed:seedling ratios on the north aspect were on unscarified-unshaded seedbeds. Thirteen times as many seeds were required to produce a 5-year-old seedling as on scarified-shaded seedbeds (Alexander 1983) (table 4).

On the south aspect, the lowest seed:seedling ratios were on the scarified-shaded and unscarified-shaded seedbeds. Seed:germinating seedling ratios were higher on the unscarified-shaded seedbeds, but first-year survival was lower. Seedling survival stabilized by the fifth growing season on these seedbeds, but compared to comparable seedbed treatments on the north aspect, it required more than 10 times as many seeds on scarified-shaded seedbeds, and nearly 5 times as many on the unscarified-shaded seedbeds to produce a 5-year-old seedling (Alexander 1983) (table 4).

Few seeds germinated and no seedlings survived as long as five growing seasons on either the scarified-unshaded or unscarified-unshaded seedbeds on the south

Table 3.—Percent total mortality by aspect, cause, and seedbed treatment (basis number of seedlings that germinated) (Alexander 1984).

Cause of mortality	Scarified-shaded			Scarified-unshaded			Unscarified-shaded			Unscarified-unshaded			Total		
	End 1st yr	End 5th yr	End study[1]	End 1st yr	End 5th yr	End study	End 1st yr	End 5th yr	End study	End 1st yr	End 5th yr	End study	End 1st yr	End 5th yr	End study
North aspect															
Drought	9.9	14.2	14.2	8.3	9.9	9.9	15.6	20.2	20.5	7.8	10.4	10.4	41.6	54.7	55.0
Clipping	7.2	7.2	7.2	6.1	6.1	6.1	1.3	1.3	1.3	0	0	0	14.6	14.6	14.6
Frost heave	0.3	6.4	6.4	0.6	4.5	4.5	0.1	0.7	0.7	0	0.5	0.5	1.0	12.1	12.1
Snowmold	0	0.9	1.3	0	2.6	2.6	0	0.7	1.2	0	0	0	0	4.2	5.1
Washout	2.0	2.3	2.3	1.0	1.2	1.2	0	0	0	0	0	0	2.9	3.5	3.5
Freezing	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.7	0.7	0.7	0.7	0.7	1.1	1.6	1.6
Heat girdle	0.7	0.7	0.7	0.9	0.9	0.9	0.1	0.1	0.1	0	0	0	1.7	1.7	1.7
Other[2]	0.9	1.9	2.0	1.4	2.5	2.5	0.6	1.8	1.9	0	0	0	2.9	6.2	6.4
Total	21.0	33.7	34.2	18.3	27.8	27.8	18.1	25.5	26.4	8.5	11.6	11.6	65.8	98.6	100.0
South aspect															
Drought	10.1	11.1	11.1	7.7	7.7	7.7	23.8	26.0	26.5	13.9	14.7	14.7	55.5	59.5	60.0
Clipping	7.0	7.0	7.0	0.5	0.5	0.5	10.8	10.8	10.8	1.2	1.2	1.2	19.5	19.5	19.5
Frost heave	0.5	2.2	2.4	0.5	0.9	0.9	0.5	0.5	0.5	0	0	0	1.5	3.6	3.8
Snowmold	0	0	0	0	0	0	0	0.2	0.2	0	0	0	0	0.2	0.2
Washout	1.2	1.2	1.2	0.7	0.7	0.7	0	0	0	0	0	0	1.9	1.9	1.9
Freezing	0	0.2	0.2	0	0	0	0.5	0.5	0.5	0	0	0	0.5	0.7	0.7
Heat girdle	1.0	1.0	1.0	1.7	1.7	1.7	4.8	4.8	4.8	2.6	2.6	2.6	10.1	10.1	10.1
Other[3]	0.2	0.5	0.5	0.7	0.7	0.7	1.0	1.9	1.9	0.7	0.7	0.7	2.6	3.8	3.8
Total	20.0	23.2	23.54[4]	11.8	12.2	12.2	41.4	44.7	45.2	18.4	19.2	19.2	91.6	99.3	100.0

[1] *Seedlings age at end of study (1982) varied from 5 to 14 years old.*

[2] *Includes isolation, damping off, gophers, and unknown.*

[3] *Includes isolation, damping off, and unknown.*

[4] *Seedlings age at end of study (1982) varied from 10 to 14 years old.*

Table 4.—Seed to seedling ratios at the end of germination, and the fifth growing seasons by seedbed treatment and aspect.

Aspect	Seedbed treatment	Germinating seedlings		Fifth year survival[1]	
		Mean	Range	Mean	Range
N	Scarified shaded	11:1	5:1 to 94:1	32:1	10:1 to 375:1
	Scarified unshaded	15:1	8:1 to 94:1	76:1	16:1 to ∞
	Unscarified shaded	17:1	5:1 to ∞[1]	72:1	29:1 to ∞
	Unscarified unshaded	42:1	9:1 to 375:1	417:1	75:1 to ∞
S	Scarified shaded	35:1	9:1 to ∞	341:1	75:1 to ∞
	Scarified unshaded	74:1	10:1 to ∞	∞	
	Unscarified shaded	19:1	4:1 to 375:1	312:1	54:1 to ∞
	Unscarified unshaded	46:1	9:1 to ∞	%	

[1] ∞ = *no germination or survival.*

aspect (table 4). Germination was low because seedbeds were too cold immediately after snowmelt, and by the time they were warm enough for seedlings to emerge, the seedbeds were too dry. Moreover, water losses from soil and seedlings were so great that reducing air and soil temperatures by shading to conserve moisture was absolutely essential to any survival, regardless of the seedbed (Alexander 1983).

At age 5 years, 800 seedlings per acre is a reasonable stocking goal for Engelmann spruce (Alexander and Edminster 1980). This is more than required for adequate stocking, but necessary to achieve uniform spacing, allow for possible future mortality, and provide options in selecting crop trees in subsequent thinnings. Numbers of seeds, based on seed to 5-year-seedling ratios in table 4, required to produce this stocking level under different seedbed conditions on north and south aspects are shown in table 5.

Seed data presented in tables 4 and 5 are minimums, based upon the exclusion of seed-eating small mammals, but not birds that consume tree seeds. All spruce-fir forests support populations of these small mammals, and any disturbance that initiates understory plant succession probably favors a buildup of these populations, particularly if slash and other downed materials are present to provide cover. Although these mammals consume considerable seed, the magnitude of losses to them is not known in the central Rocky Mountains. It seems reasonable to expect that under poorest conditions in the central Rocky Mountains, losses could be as high as 50% of the viable seed produced in a good seed year.

RECOMMENDATIONS

Equations [2] and [3] are useful for estimating potential periodic annual spruce seed production in stands with different characteristics, but the standard errors of estimate approximated from the untransformed residuals are very high. Therefore, the resolution between poor to heavy seed crops is not very good. These equations also do not provide the means for estimating the seed crop rating for any individual year. In some years, seed crops will be total failures, and, even in years of good overall seed production, not all locations will produce good to bumper seed crops.

Table 5.—Number of viable seeds required to produce 800 5-year-old Engelmann spruce seedlings per acre in relation to seedbed treatment and aspect.[1]

Seedbed treatments	Aspect	
	North	South
Scarified shaded	25,600	272,800
Scarified unshaded	60,800	∞[2]
Unscarified shaded	57,600	249,600
Unscarified unshaded	333,000	∞

[1] *Data presented are based upon the exclusion of seed-eating mammals. If these animals are not excluded, numbers of seed required should be increased by 100%.*

[2] *∞ = no survival.*

Figure 4 is useful in approximating Engelmann spruce seedfall into clearcut openings. However, while the curves developed from equation [6] fit the trends in seed dispersal very well, there is considerable variability around the curves. This means that estimates of seedfall for an individual year at any location may vary considerably from actual seedfall.

The data presented in tables 4 and 5 were derived from one habitat type at one location, the Fraser Experimental Forest. In the absence of better information, they can be used to approximate what might occur on similar seedbeds in this habitat type elsewhere. However, while the viability of seed used in this study was good, the criterion that 125 viable seeds be sown on each seedbed each year was based on laboratory germination tests. Actual viability in the field, therefore, may have been lower, in which case the seed:seedling ratios are too low. Small mammals that consume tree seed were excluded from the seedling study, but exclosures suitable for research purposes are not practical for operational timber sales. The effectiveness of other rodent abatement procedures, such as treating seed or baiting, is not known for spruce-fir forests in the central Rocky Mountains. Moreover, little is known about seed predation by small mammals in spruce-fir forests. Estimates of possible losses to seed-eaters are highly speculative, therefore. Seed:seedling ratios vary considerably with climatic changes. These data cover a period of time 1968 to 1982, but represent only the weather conditions during that period. The distribution of summer precipitation varied more than the amount. Summer rainfall was more erratic during the period 1974 through 1980 than either before or after. No seedlings that germinated after 1973 survived on the south aspect (Alexander 1984).

In estimating the size of clearcut opening likely to restock naturally within a 5-year period, the following assumptions were made based on the data presented.

1. Accumulative production of 500,000 to 1,000,000 sound seeds per acre in uncut stands over a 5-year period is not an unreasonable expectation.
2. Fifty percent of the viable seeds produced will be lost to seed-eaters.
3. At age 5 years, 800 seedlings per acre is a desirable stocking goal.
4. Figure 4 is a reasonable estimate of the distance seed is dispersed from source.

On north aspects, the effective seeding distance on scarified-shaded seedbeds is about 200 to 350 feet from the windward stand edge. Openings 300 to 450 feet wide (assuming an effective seeding distance of 50 to 100 feet from the leeward stand edge) should adequately restock within 5 years. The effective seeding distance on scarified-unshaded and unscarified-shaded seedbeds on the north aspect is about 150 to 250 feet from the windward stand edge, with openings 200 to 350 feet wide restocking adequately within 5 years. On unscarified-unshaded seedbeds on the north aspect, and all seedbeds on the south slope, the effective seeding distance is so limited that clearcutting, with the expectation of adequate natural restocking in a reasonable period of time, is not a viable option. Under these conditions, a shelterwood cutting method is recommended for even-age management with natural reproduction.

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Engelmann spruce seed production and dispersal, and seedling establishment in the central Rocky Mountains indicate that in the *Abies lasiocarpa/Vaccinium scoparium* habitat type, shaded, mechanically scarified, mineral soil seedbeds on north aspects can be adequately restocked naturally within a 5-year period in clearcut openings 300 to 450 feet wide. With shade or scarification alone, size of opening that will restock is reduced to 200 to 350 feet. The effective seeding distance is so limited on unshaded natural seedbeds on north aspects and on south aspects regardless of the seedbed conditions that the expectation of natural restocking in a reasonable period of time with clearcutting, is not a realistic option.

Keywords: *Picea engelmannii,* natural forest regeneration

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Rocky Mountain Forest and Range Experiment Station

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United States
Department of
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Forest Service

**Rocky Mountain
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Fort Collins,
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**General Technical
Report RM-135**

Management and Utilization of Arid Land Plants:

Symposium Proceedings

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REUNION SOBRE MANEJO Y UTILIZACION DE LAS PLANTAS DE ZONAS ARIDAS

**February 18-22, 1985
Saltillo, Mexico**

ABSTRACT

Patton, David R.; Gonzales, Carlos E.; Medina, Alvin L.; Segura, Luis A.; Hamre, R. H., tech. coords. Management and utilization of arid land plants: symposium proceedings; 1985 February 18-22; Saltillo, Mexico. Gen. Tech. Rep. RM-135. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1986. 113p.

These proceedings contain 19 papers presented as part of a continuing cooperative effort in forestry and related resources between Mexico and the U.S. Primary species discussed include jojoba, guayule, palms, prickly pear, candelilla, mesquite, buffalo gourd, creosotebush, Indian ricegrass, and yerba del manso. Papers are in the language of the author (Spanish or English) with an abstract in the other language.

Keywords: Arid land plants, desert agriculture

USDA Forest Service
General Technical Report RM-135

September 1986

Management and Utilization of Arid Land Plants:
Symposium Proceedings

REUNION SOBRE MANEJO Y UTILIZACION DE LAS PLANTAS DE ZONAS ARIDAS

February 18-22, 1985
Saltillo, Mexico

Technical Coordinators:

David R. Patton
Carlos E. Gonzales V.
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Cosponsors

Mexico:
Subsecretaria Forestal, a traves del
Instituto Nacional de Investigaciones
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Rocky Mountain Forest and Range
Experiment Station, and Southwestern
Region, Forest Service, U.S.
Department of Agriculture

Rocky Mountain Forest and Range Experiment Station
Forest Service, U.S. Department of Agriculture

Foreword

In 1981, the USDA Forest Service and SARH Sub-secretaria Forestal de Mexico signed a five-year plan of cooperation to exchange information to improve the professional and technical capabilities of scientists in both countries. The plan included sponsorship of a symposium on inventory, management, and utilization of arid land plant species with economic value. The symposium was held February 18-21, 1985 at Saltillo, Mexico. Papers were presented during a three day meeting with one day devoted to a field trip to the Campo Experimental Station "La Sauceda." Over 200 scientists, technicians, and administrators, attended the symposium. This General Technical Report includes papers presented in the language of the author (English or Spanish) with a summary at the end in the other language.

International meetings require considerable preparation and the involvement of many people. Recognition for the successful symposium in Saltillo must be given to Luis Segura, Lorenzo Maldonado, and Miguel Caballero from Instituto Nacional de Investigaciones, and Bob Partido, Reggie Fletcher, Bob Hamre, and Diane Prince from USDA Forest Service. Carlos Gonzales was our counterpart in Mexico for organizing the meeting and selecting papers. All the papers presented represent the opinion of individual authors who were responsible for their own peer review, manuscript preparation, and editing.

DAVID R. PATTON and ALVIN L. MEDINA
Technical Coordinators

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Potencial del Guayule Bajo Cultivo en Zonas Aridas del Norte de Mexico[1]

Dr. Alfónso Lopez Benítez[2]

Resumen.--El guayule, especie vegetal que se encuentra en parte de las zonas áridas de México, es potencialmente util debido a que contiene en promedio un 10% de hule natural, lo que según reportes oficiales, representa una reserva de 300 mil toneladas de hule natural, mientras que México actualmente requiere importar alrededor de 40,000 toneladas anuales.

El aprovechamiento actual de la especie es nulo y para su explotacion se requieren aún varios estudios, por lo cual se han realizado una serie de investigaciones agronomicas que cubren diferentes aspectos del cultivo del guayule, algunas de las cuales se presentan en este trabajo.

INTRODUCCION

Convencionalmente en México se ha considerado como zona árida aquella área geográfica que recibe una precipitación pluvial anual de no mayor de 250 mm, y como semiárida aquella que recibe una precipitación entre 250 mm. y 500 mm.

En la República Mexicana existen aproximadamente 809,000 Km. cuadrados con este tipo de zonas, en las cuales se calcula que vive el 17% de la población del país, cuyos habitantes economicamente activos se dedican principalmente a actividades de subsistencia como: agricultura rudimentaria, pastoreo y recolección de especies vegetales silvestres utilizables. Esto se traduce en miseria, migración hacia los centros urbanos y desperdicio de recursos naturales y humanos

Existe sin embargo, en buen número de especies vegetales nativas potencialmente utilizables cuyo manejo y explotación "in situ" asi como su domesticación y cultivo son potencialmente una considerable fuente de trabajo y recursos económicos para esas zonas consideradas como marginadas.

Una de esas especies es el guayule cuya distribución natural esta confinada a pendientes y laderas con suelos calcáreos y pedregosos con altura de 900 a 2300 msnm; una precipitación media anual de 250 a 380 mm y una variación de temperatura de -10°C en invierno a 40°C en verano.

La importancia que tiene el guayule para México consiste en 1). En su habitat natural contiene en promedio un 10% de hule natural, 2). En las zonas áridas del norte de México, existen aproximadaments 3 millones de toneladas de arbusto equivalentes a 300 mil toneladas de hule natural (según informe de CONAZA 1972-1976), 3). En promedio México produce solo el 10% de subnecesidades internas de este producto, por lo que tiene que importar anualmente alrededor de 40,000 toneladas. Con la explotación del guayule en las zonas áridas se vería beneficiada la población existente en ellas.

Actualmente el aprovechamiento de este recurso es nulo y para explotar su potencial se requiere de investigación para desarrollar la tecnología necesaria, evaluar la factibilidad económica de su explotación y evaluar su repercusión socioeconómica.

Las áreas de investigación que hasta ahora se han atendido son: 1). Producción de planta y establecimiento de lotes experimentales de riego y de temporal, 2). Densidad de población por hectárea y edad óptima para la cosecha, 3). Estudios de fertilización, 4). Plagas y enfermedades, 5). Mejoramiento Genético y 6). Formación de un Banco de Germoplasma.

Entre los problemas primero abordados fue el mejorar la germinación de la semilla, para lo cual, primero se limpia de residuos florales, se trilla, y se eliminan las brácteas de la semilla hasta obtenerla limpia, posteriormente se le sumerge en agua por 8hs, y se le aplica un tratamiento de hiploclorito de sodio (Na O Cl) al 3% durante 30 minutos y para semilla nueva recién cosechada se le da un tratamiento adicional de ácido gibberelico de 100 ppm. durante 3 horas. Con lo que se obtiene una germinación mayor del 80%.

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[1] Ponencia presentada en la Reunión Sobre Manejo de Plantas en Zonas Aridas. Saltillo, Coahuila, México. Febrero 18-22, 1985.

[2] Ph.D. Jefe del Programa de Guayule del Departamento de Fitomejoramiento de la UAAAN. Saltillo, Coahuila. México.

Con esto se puede obtener la cantidad de plántulas necesarias en invernadero para establecer los lotes experimentales deseados para cualquier estudio.

Con el objeto de obtener información sobre el cultivo del guayule bajo condiciones de temporal y de riego, y evaluar su potencial de producción, se han realizado una serie de estudios agronómicos que cubren diferentes aspectos del cultivo de esta planta y que en forma resumida se presentan a continuación:

1). Evaluación de tres densidades de población por hectárea bajo condiciones de temporal.

Con una precipitación medio anual de 325 mm se estableció este estudio en el que se utilizaron dos espaciamientos entre surcos (71 y 61 cm.). Con tres distancias entre plantas que dieron densidades de 23,000, 28,000 y 33,000 plantas por hectárea. Los parámetros evaluados fueron altura de planta, diámetro de copa, contenido de resinas y contenido de hule. Low datos obtenidos indicaron que a los cuatro años de edad no había diferencias estadísticas entre las diferentes densidades, pero en cuanto a desarrollo vegetativo la densidad de 33,000 plantas por hectárea fue ligeramente superior.

2). Respuesta del guayule a 4 niveles de riego en tres densidades de población por hectárea.

Los niveles de riego fueron cada 45 días, cada 60 días, cada 120 días y un riego por año. Las densidades de población fueron 40,000, 55,000 y 65,000 plantas por hectárea. Los parámetros evaluados fueron altura de planta, diámetro de copa, contenido de hule y contenido de resinas. Los datos obtenidos indicaron diferencias estadísticas para riego y densidad de población. Siendo el tratamiento de riegos cada 60 días y 40,000 plantas por hectárea estadísticamente superior en cuanto a desarrollo vegetativo y contenido de hule.

3). Determinación de contenido de hule diferentes materiales.

En su gran mayoría los materiales hasta ahora evaluados para contenido de hule provienen de poblaciones silvestres donde existe una amplia variación genética.

Se han colectado 2,850 de las que se han analizado por contenido de hule 322 colectas destacando los del estado de Durango. Las pruebas preliminares de contenido de hule indican que que bien pueden compararse con algunas de las variedades mejoradas obtenidas del Laboratorio Nacional de Servicio de Semillas de Estados Unidos.

El potencial de producción de hule del guayule puede apreciarse mejor en una prueba de contenido de hule de 15 diferrentes genotipos, que se realizó bajo un diseño experimental de bloques completos al azar con cuatro repeticiones y una densidad de población por hectárea de 27,000 plantas con dos riegos en primavera. En esta prueba a los tres y cuatro años de edad, el genotipo N-593 destacó por su porte bajo, 41.6 cm. de altura y su alto porcentaje de hule en base a su peso seco, 11.4% y 12.17%. También resultaron consistentemente altos en contenido de hule en dos años los genotipos N-573, G-11624 y G-11646. En cuanto a contenido de hule en gramos por planta los genotipos G-11604 y G-11605 resultaron con mayor contenido de hule. Con una producción estimada por hectárea de 2.3 y 2.2 toneladas por hectárea respectivamente. Esta producción en un período de tres años puede considerarse aceptable. Sin embargo existen algunos otros materiales que aparentemente superan bajo condiciones de tamporal a los mejores genotipos aqui evaluados como son los introducciones 76023, 76060 y 76028-5 con 13.62, 13.60 y 13.61 porciento de hule respectivamente.

Summary.-- Guayule, a shrub species found in arid zones of Mexico, has potential uses given its mean content of 10% natural rubber. Official reports indicate national reserves of approximately 300,000 tons of natural rubber. Mexico produces 10% of its internal needs, and imports almost 40,000 tons of rubber annually. The use of guayule as a resource is currently virtually non-existant, and to develop its potential will require various studies dealing with the different aspects of cultivation, some of which are presented here.

Management and Improvement of Guayule Germplasm[1]

Himayat H. Naqvi[2]

Abstract.--Guayule (*Parthenium argentatum* Gray) is a potential rubber producing crop for the arid land areas. The ecologically fragile natural guayule populations that were exploited in the past need to be protected as valuable biological resources, and not used as raw material for industry. At UC Riverside, procedures have been developed to properly manage and utilize guayule germplasm, and to further improve it through selection and hybridization. Significant progress has been made in the domestication and commercialization programs.

INTRODUCTION

The world demand for rubber has been steadily increasing since its original discovery by Charles Goodyear in the middle of the last century. *Hevea brasiliensis*, a native of South America, provided most of the original supplies of commercial rubber. The plant is now successfully domesticated in tropical Asia where it dominates the world market. In addition to *Hevea*, many other plants, mostly belonging to families Moraceae, Euphorbiaceae, Asclepiadaceae, Apocyanaceae, and Asteraceae, were investigated and occasionally utilized as local sources of rubber. The most extensive use, thus far, of any North American rubber plant has been that of guayule (*Parthenium argentatum* Gray, of the family Asteraceae), a Texan-Mexican shrub that has been going through ups and downs of research and development efforts since at least the middle of the 19th Century.

Historical Aspect

The guayule plant was scientifically discovered in Texas by Dr. J. M. Bigelow in 1852, while he was attached to the Mexican Boundary Survey Commission. It was later botanically described by Professor Asa Gray of Harvard University. The plant was, however, known to the natives on both sides of the border long before that. The conquering Spaniards, reaching Mexico in the 1500s, noted a game played with a small, very resilient ball made of pure rubber obtained by communal mastication of the bark of guayule and some other related plants.

Another primitive use of guayule was as a fuel that may be partly responsible for its absence in places where it would be naturally expected. Due to its high resin content, the plant burns with a fierce smokey flame so that whenever it was available, it was invariably used as fuel for the crude Mexican adobe smelters, light torches, home heating, and bread ovens. This practice was later stopped or slowed down when the value of the plant was known, but by then, thousands of acres of guayule had already been depleted.

Commercial Exploitation

According to Lloyd (1911), guayule rubber was brought to public attention for the first time in 1876 by an exhibition sent from Durango, Mexico, to the Centennial Exposition at Philadelphia. The Natural History Society of Mexico also took up the study of the plant in the same year and reported the presence of rubber of good quality in its bark. During the next few years, many companies were established in the United States and Mexico, and small-scale rubber-testing programs were carried out. The earliest efforts seem to have centered around San Luis Potosi in Mexico, which may be regarded as the birthplace of industrial guayule rubber. In 1902, a factory was established at Jimulco by the Compania Explotadora de Caucho Mexicano that put the guayule rubber on the market for the first time in 1905. At about the same time, certain American businessmen successfully adapted the mechanical extraction method that used a pebble mill. During the next few years, many factories were built at Torréon, San Luis Potosi, Saltillo, Monterey, Gomez Palacio, and Jimulco. Factories were later established at Marathon, Texas, and elsewhere. All of these factories were utilizing wild guayule shrub from the wild stands in Mexico and Texas. From 1910 to 1946, Mexico exported more than 68 million kg of guayule rubber to the United States, and much of that rubber was used in the manufacture of automobile tires.

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[1] Paper presented at the Symposium on Management and Utilization of Arid Land Plants. [Saltillo, Mexico, February 18-22, 1985].

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Natural resources are not unlimited, especially under arid conditions. Soon, the wild populations of guayule shrub were depleted to a point where most of the factories were forced to close down (Hammond and Polhamus 1965). The four owned by the Continental Rubber Company remained open for a little longer, but they foresaw the need for carrying out cultural operations that were initiated in 1910. These operations were later transferred to San Diego, California, then to Arizona, and finally to Salinas, California, where cultural and chemical operations continued for the next few years. During World War II, these operations of the Intercontinental Rubber Company were taken over by the U.S. Forest Service to carry out the wartime Emergency Rubber Project. More than 40,000 hectares of guayule were planted over the next 3 years and an extensive research and development program was initiated to study all phases of guayule commercialization activity.

At the end of the war, the entire rubber outlook changed. In December 1945, funds for the guayule project were frozen and the project was ordered liquidated in its entirety as of December 1946. This resulted in the destruction of an estimated 10 million kg of rubber standing in the field. Limited research activity did continue in a few organizations in the U.S., Mexico, and some other countries, but without major breakthroughs.

Present Outlook

The high mobility of modern civilization depends mainly on two commodities, namely the petroleum as a liquid fuel for vehicles and the rubber which is used for tires and other components of these engines. These two products also play an important role in other aspects of high technology and, as a result, have become symbols of economic and strategic security for most countries of the world.

Presently, there are two main classes of rubbers that are commonly used in every day life:

1) Natural rubbers that are derived from plant sources, especially Hevea brasiliensis, and

2) Synthetic rubbers derived from petroleum by-products. Although the overall demand for synthetic rubbers has been on the rise, natural rubber, nevertheless, is preferred due to improved elasticity, resilience, tackiness, and low heat buildup. It is, therefore, essential for the manufacture of high quality airplane and automobile tires as well as for other high duty industrial components.

Hevea brasiliensis, the current major source of natural rubber in the world, is a tropical tree that cannot be grown in the United States and other arid and semiarid parts of the world. Most such countries have to import natural rubber from tropical Asia, and other parts of the world. The United States, alone, spends nearly one billion dollars annually to buy this strategically essential commodity from outside sources, causing lots of economic and security concerns. These concerns turned into fears during the Arab Oil Embargo of the early 1970's, and attention was once again turned to find alternate sources of natural rubber that can be grown in the semiarid environment. The U.S. National Academy of Sciences (1977) intervened and appointed a panel of experts from the U.S. and Mexico to consider guayule as a possible alternative. The panel strongly recommended guayule to be grown as a natural source of rubber in the United States and other countries with semiarid environments. This initiated a series of new research and development projects in the United States that also stimulated many researchers in other countries to follow suit. The Congress of the United States passed the Native Latex Act in 1979, providing money for guayule work. USDA, NSF, and other organizations allocated funds for guayule research that came into national and international focus once again. The Critical Agricultural Materials Act of 1984 ensures further efforts in this direction. New scientific knowledge and experience acquired during the past few years has shown that economic and technological feasibility is near. Recent analysis of guayule rubber has shown that it is equal to hevea in physical as well as chemical properties, and can be substituted for hevea in most applications. The inherent low concentration of rubber in the early germplasms is being improved through a major breeding program at the University of California, and other agronomic investigations are being carried out at the universities and the Agriculture Research Service Laboratories in the four southwestern states. A chemical extraction process has been developed by the Texas A&M University, and research is also being conducted to determine the value of resins, bagasse, and other by-products to enhance commercialization efforts.

CURRENT STATUS OF GUAYULE GERMPLASM

Our brief survey of guayule native populations in Mexico (Naqvi and Hanson, 1983a), and that of Tipton and Gregg (1982) for Texas populations, revealed a wide range of variability in rubber content and environmental responses in various populations. Rubber contents varied from as low as 6% to over 19% on the dry weight basis. Guayule populations were generally found at altitudes from 700-3,000 m, and topographic and climatic conditions also varied from place to place. All these varied niches and wide distances between most guayule populations provided excellent opportunities for the development of ecotypes and races resulting in a significant variability within and between populations. Using raw seed from these populations for whatever purpose can be a wasteful experience. On the other hand, bringing these valuable sources of germplasm into a systematic improvement program can be a useful proposition. An improvement program is also essential for commercializing guayule as a rubber-producing crop in today's high industry requirements. It is estimated that the existing sources of guayule germplasm need at least two-fold improvement in rubber content before it can be accepted as a commercial crop. The potential

Table 1.--Early guayule selections[1] included in comparisons provided by Hammond and Polhamus (1965).

Selec. #	Synonym	Applicable information
11591	---------	Open-pollinated selection from 4265-I.
11600	---------	Do.
11604	---------	Do.
11605	---------	Do.
11609	---------	Do.
11619	---------	Do.
11633	A-48124	Hammond collection having smaller plants, but higher total rubber.
11634	---------	72-chromosome; from open-pollinated, 36-chromosome cross between SP-7 and SP-8
11635	596	72-chromosome controlled cross between 54-chromosome 4265-I plant and a plant of 36-chromosome.
11646	A-48121	Hammond collection with superior performance at Salinas.
11693	N-563	72-chromosome cross found among plants in a 54-chromosome 4265-I selection.
11701	---------	72-chromosome descendant of open-pollinated cross between 54-chromosome 4265-I and 36-chromosome unknown.
A-48115	12231	Hammond collection.
A-48116	N-576	Hammond collection with good performance at Salinas.
A-48118	---------	Hammond collection.
A-48121	11646	See 11646.
A-48124	11633	See 11633.
A-48143	---------	Hammond collection from northern Zacatecas. Good at Salinas.
N-396	---------	Single plant selection from Hammond collection.
N-566	---------	Open-pollinated selection from 4265-I.
N-575	A-58143	See A-48143.
N-576	A-48116	See A-48116.
N-596	11635	See 11635.
12229	---------	From single-plant selection from progeny of open-pollinated 2106 and guayule *Parthenium tomentosum* var. *stramonium*.
12231	A-48115	See A-48115
593	---------	Commercial variety developed by the Intercontinental Rubber Company.
4265	---------	Collected by Powers in Durango in 1942. Highly variable.
4265-I	---------	Selected from 4265 by Johnson; 54 chromosomes; variable.
4265-II	---------	Open-pollinated selection from 4265.
4265-X	---------	Selected from 4265-I by Taylor and Benedict; 72 chromosomes; higher rubber content and more uniform than 4265-I.
4265-XF	---------	Seed increase of selected plants from 4255-X.

[1] Seeds of most of these strains have been placed in storage at the USDA Laboratories at Fort Collins, Colorado.

is there if it is properly exploited without damaging the fragile arid ecosystems inhabiting guayule.

The first step in any management and improvement program is to locate and collect the existing sources of guayule seed. The largest reservoir of guayule germplasm exists in nature growing mainly in the Chihuahuan Desert and adjacent areas in southern Texas and northcentral Mexico (Naqvi and Youngner, 1984). Due to sporadic cultural operations during the past 70 years, some germplasm sources do exist elsewhere. One of the important sources is maintained at the USDA Seed Storage Laboratory at Fort Collins, Colorado (USA). These include many USDA guayule lines that have been salvaged from the Emergency Rubber Project of the 1940s and others, and are available to researchers (table 1). Some germplasm is also available from other public and private research groups, but most of them stem from the USDA lines and/or from collections made from the wild guayule stands. Some recent collections include those made by Rollins in 1976, and Naqvi and Hanson in 1977 (Knoblock 1979). Most of these sources of seed have been accumulated at the University of California, Riverside, and are being managed and tested accordingly. In 1982, seven certified varieties of guayule germplasm were released jointly by USDA and the University of Arizona, Texas A&M University, New Mexico State University, and the State of California (Niehaus 1983) and are available to growers (table 2).

Table 3 gives a comparative evaluation of the three of these lines grown at Riverside, Tucson, Mesa, and Las Cruces. Two points are evident: (1) there is significant variability in rubber content within and between these lines, and (2) the Riverside samples are more similar to those in Arizona in terms of rubber content. Las Cruces plants show higher values. Rubber, like other quantitative traits, is influenced by environment to a significant extent.

Table 2.--Seven cultivars of guayule released jointly by the Agricultural Experiment Stations of Arizona, California, New Mexico, and Texas, and the USDA-ARS (adapted from Niehaus 1983).

Cultiv.#	Description	Cultiv.#	Description
N-565	High rubber-yielding at Shafter, 1957 Plant uniformity rating,[1] 94.0% Percent rubber,[2] 7.3, 6.2, 8.4 Rubber yield,[3] 1369 lbs/acre	11605	High rubber yielding at Salinas, 1950s Plant uniformity rating, 70% Percent rubber, 6.8, 4.4, 8.4 Rubber yield, 1125 lbs/acre
11619	High rubber yielding at Salinas, 1950s Plant uniformity rating, 95% Percent rubber, 4.4, 3.4, 7.0 Rubber yield, 1319 lbs/acre	12229	High rubber yielding at Shafter, 1958 Plant uniformity rating, 95% Percent rubber, 5.3, 4.4, 6.0 Rubber yield, 1042 lbs/acre
11591	High rubber-yielding at Salinas, 1950s Plant uniformity rating, 95% Percent rubber, 4.4, 3.4, 7.0 Rubber yield, 1250 lbs/acre	N-576	High rubber yielding at Salinas Plant uniformity rating, 95% Percent rubber, 5.6, 4.9, 7.1 Rubber yield, 1030 lbs/acre
11604	Plant uniformity rating, 90% Percent rubber, 5.5, 4.8, 8.4 Rubber yield, 1348 lbs/acre		

[1] Plant uniformity rating conducted at Arizona and New Mexico. [2] Percent rubber values for Tucson, Mesa, and Las Cruces, respectively, at 3 years. [3] Rubber yield values are averages for 3 locations at 3 years.

PROPAGATION AND AGRONOMICS

Seed Germination

As a member of the family Asteraceae, the seed-bearing flowers in guayule are arranged on a capitulum. There are five female flowers in a capitulum and, theoretically, one seed per female flower. Some of these seeds, however, may be lacking embryos. Guayule is a long-day plant, and flowering is mainly dependent upon the irrigation frequency. In nature, of course, it will depend upon the precipitation. It is a prolific seed producer and under optimum moisture conditions can produce 3-4 crops during the growing season that begins in mid-spring and lasts to early fall. When the floral heads are mature, they can be easily collected manually or with the help of a mechanical device.

An unthreshed guayule seed unit consists of an achene, two attached staminate florets and a subtending bract. The first step, therefore, is to separate the achene from its enclosing structure. For small samples, the seed units are threshed between a rubber abrader and the Tyler Standard 20- and 10-mesh sieves. For larger lots, a mechanical thresher can be adopted. Forsberg #2 Huller equipped with rubber cylinder and liner proved useful in many organizations. After threshing, the chaff is removed from the seed using a Dakota Blower or a clipper office tester equipped with appropriately sized sieves (Toukdarian _et_ _al_. 1983).

Table 3.--Variability in rubber content in three guayule lines grown at UCR, and comparative evaluation with the same lines grown at Tucson, Mesa, and Las Cruces. These three lines are among the seven USDA lines released for commercial purposes.

	11605		11604		11591	
Sample No.	Rubber (%)	Height (cm)	Rubber (%)	Height (cm)	Rubber (%)	Height (cm)
1	4.62 A	33.00	7.37 A	40.00	7.00 A	38.00
2	4.27 A B	38.00	5.60 B	33.00	5.62 B	40.00
3	4.00 B C	41.00	5.60 B	25.00	5.35 B	37.00
4	3.95 B C D	33.00	5.50 B	45.00	5.07 B C	38.00
5	3.92 B C D	33.00	5.27 B	36.00	4.60 C	41.00
6	3.65 C D E	50.00	4.20 C	35.00	3.85 D	32.00
7	3.55 D	42.00	4.10 C	43.00	3.25 E	39.00
8	2.67 E	29.00	4.52 C	44.00	2.70 E	33.00
x at UCR	4.04	43.30	5.27	37.60	4.98	37.20
SD±	0.32	11.40	1.14	6.70	1.21	3.19
LSD @ 5%	0.3811		0.5425		0.5736	
x Tucson	4.4	70% planting uniformity rating	5.5	90% planting uniformity rating	4.4	95% planting uniformity rating
x Mesa	3.4		4.8		3.4	
x Las Cruces	7.0		8.4		7.0	

A large number of guayule seeds are empty, i.e., without embryos. These empty seeds are lighter than the filled ones and are, to some extent, removed with the chaff during the cleaning operations. For a complete removal of these empty seeds, a small test gravity table can be used effectively. Another way of overcoming this problem is to soak the seeds for 1-2 minutes in an organic solvent of low specific gravity. The heavier filled seeds will sink to the bottom and the light, empty seed will float at the top and can be discarded. Pentane, isopentane, and some alcohols proved very effective without causing damage to the seeds. Table 4 shows the result of one such test.

Guayule seed has inherent dormancy and needs special pretreatment in order to germinate. Appropriate procedures have been developed to overcome this problem (Naqvi and Hanson 1980, 1983b). Seeds are soaked and washed in water to improve permeability and remove toxic seed inhibitors (Naqvi and Hanson 1982). They are then treated with a mixture consisting of equal parts of sodium hypochlorite and gibberellic acid for 2 hours. The concentration of sodium hypochlorite used for this purpose depended upon the postharvest age of the seed. For freshly harvested seeds, a concentration of 1.0% by available chlorine is most suitable. With increasing age, the concentration should be decreased accordingly. Two-hundred ppm of gibberellic acid serve the best purpose for seed of all ages. After pretreatment, the seed can be directly sown or dried and kept for later use. The results of a germination test with one seed lot is shown in table 5.

Field Planting

Pretreated guayule seed can either be planted directly in the field or grown into seedlings in a greenhouse and later transplanted in the field. Direct seeding in the field has not been very successful at the moment due to low competitive ability of young guayule seedlings and their sensitivity to drought conditions. Some degree of success in direct seeding has been achieved, utilizing a new concept known as "fluid drilling." This involves the direct sowing of pretreated and partially germinated seed into the soil, using a gel carrier that enables the guayule seedlings to become established rapidly and help it to compete with the much faster-growing weeds. A constant mist for the first few days helps the young seedlings to overcome drought stress. This process still needs further improvement to become commercially acceptable.

Table 4.--Separation of filled guayule seed in organic solvents of different specific gravities.[1]

Organic solvents used for soaking	Percent germination in: Top fraction	Bottom fraction
pentane	1.5	82.0
iso-pentane	4.0	81.0
benzene	13.0	92.0
ethanol	34.0	87.0
chloroform	46.0	71.1

[1] Approximate number of guayule seed were soaked in each solvent, and the two fractions thus separated were each germinated separately and percent germination determined thereof. The seed that germinated were considered filled seed with embryos, the rest were empty seed.

Table 5.--Comparative effects of various treatments on germination and radicle growth in three-month-old wild guayule seed collected near San Pedro del Gallo, Durango, Mexico.

Seed treatment	Germination (%)	Radicle growth (mm)
Unwashed	59.0	5.1
Washed	63.0	5.3
Washed + NaOCl	79.0	5.7
Washed + GA_3	82.0	6.4
Washed + NaOCl + GA_3	92.0	7.0

For all practical purposes, guayule seedlings are raised in the greenhouses. Pretreated seeds are sown in flats filled with well-drained media and kept moist in the greenhouse. Seeds germinate in a week and are pricked in individual pots. Seedlings can be transplanted in the field in about 6-8 weeks. Various stages of propagation and greenhouse management can be mechanized to save time and money. Field transplanting can also be accomplished, using mechanized farming equipment. Field design and management will depend upon the objectives of the experiments to be conducted. In general, about 25,000 plant per hectare have shown good results (Hanson *et al.* 1979; Siddiqui *et al.* 1979).

GERMPLASM IMPROVEMENT

Selection Procedures

Existing guayule germplasm occurs in various ploidy levels, including diploids (2N = 36), triploid (2N = 54), tetraploids (2N = 72), and even higher levels. In general, the diploid germplasm is sexual in reproduction, but higher ploidy plants are mostly apomictic. Although various ploidy level plants occur in nature, apomictic tetraploids are more prevalent. Most of the USDA lines, which were originally selected from the wild populations, are facultative apomicts. A recent screening of 19 USDA lines growing at UCR revealed a range of 3-7% rubber in these plants. Further analysis of variance showed that plants were significantly different within and between most lines in terms of rubber contents (Naqvi 1985). As a result, they offer a better opportunity for selections that may prove relatively more stable in time.

Improvement of the existing guayule germplasm is carried out through standard selection procedures. Plants under selection are grown in experimental plots at Riverside and Palmdale. The latter is our closest version of a high desert situation located at an average altitude of about 1,000 m. In general, plants are grown at the rate of about 25,000 plants per hectare and maintained at optimum growing conditions. In southern California, summers are dry and winters are wet. As a result, irrigation is only applied during the summers on an if-needed basis. For USDA lines and other sources that have passed through some degree of selection, an average of eight plants are selected per line and analyzed for rubber and other traits. For other sources of seeds, each plant is selected and analyzed.

Presently, the major selection criteria include improved yield (biomass and rubber), cold tolerance and disease resistance. Plant height and width are the usual parameters measured for biomass determinations, although fresh and dry weights are considered frequently.

Two parameters are considered for rubber monitoring: (1) rubber quantity based on percent dry weight of the sample, and (2) rubber quality based on molecular weight determinations of the rubber in samples. Plant sampling is done in such a way that it does not destroy the entire plant. A number of branches of average diameter of 1.0 cm are taken from the lower portions of the plant, dried in a forced-air oven at 60°C for 48 hours, and then ground in a Model 4 Thomas-Wiley Laboratory Mill, using a 2-mm mesh screen. Freezing the dried samples in liquid nitrogen prior to grinding can facilitate grinding and avoid too frequent cleaning of the equipment. For quantitative rubber analysis, we use a modified photometric procedure (Perry et al. 1983; Naqvi et al. 1984). This procedure has the advantage over other standard procedures in that it can utilize as low as 1.0 g sample, and the measurements compare well with others (Banigan et al. 1982; Black et al. 1983). Rubber molecular weight, as a measure of its quality, is determined through gel permeation chromatography using ultrastyragel columns (Campo-Lopez and Agulo-Sanchez 1975; Naqvi et al. 1984). Tetrahydrofuran is used as a solvent for rubber extraction as well as a solvent system in the GPC. Chromatograms obtained for each sample are compared with the polystyrene standards prepared earlier and converted into polyisoprene equivalents using standard calculations.

Seeds are collected from plants with high rubber contents and other desirable traits. These seeds are germinated and planted in the field for the second cycle of observation and testing. The selected progeny is put through a replicated yield trial and the final selections are increased and distributed as improved guayule cultivars. Selections for improved cold tolerance and disease resistance are also tested in accordance with the prescribed breeding procedures.

Table 6.--Some high-rubber guayule selections made at UC Riverside as compared to USDA var. 575 used as a control. All new selections have higher average rubber with less variability within each entry.

Entry #	Mean Rubber[1]	Range
P-40-101	10.2	9.2 - 11.2
P-48-13	8.9	7.1 - 11.0
P-48-24	10.6	9.0 - 11.7
P-50-51	7.7	7.1 - 8.4
N-575[2]	6.9	5.5 - 6.9

[1] Average of 7-8 samples, each replicated twice.

[2] From published data (Naqvi 1985). This variety exhibited highest % rubber in an earlier trial.

Table 6 shows the results of one set of second cycle high-rubber selection progeny. It is evident that these lines are relatively more uniform with much higher population mean than those in the first cycle in just one cycle of selection pressure. A few cycles of selection should ultimately produce germplasm lines with high rubber and other desirable traits. Figure 1 shows some of these selections growing in the field at UC Riverside.

Interspecific Hybridization

In addition to guayule, genus Parthenium also includes 16 other species that range in gross morphology and habit from an ephemeral annual to perennial trees, and also in ecological requirements inhabiting deserts to subtropics (Rollins 1950). Despite these differences, most species have similar floral structure and chromosome numbers, and are easily crossed with each other producing fertile hybrids. Most other species of Parthenium, however, do not have significant quantities of high quality rubber, although they do possess other characteristics that are desirable for a guayule germplasm improvement program (Youngner et al. 1985). These include increased biomass associated with increased total rubber per plant, cold tolerance, and resistance to disease and pest infestations. Table 7 provides a list of Parthenium species used in the hybridization program at UC Riverside. We are currently using at least three species for biomass improvement. These include P. schottii, P. tomentosum, and P. fruticosum, and are all trees reaching up to 8 m in height (Naqvi 1982; Naqvi et al. 1983, 1984). These plants are also sources of improved disease and pest resistance (Cheo and Beupre 1981). P. incanum, P. integrifolium, and P. alpinum are used for imparting cold tolerance to guayule. Most of these species occur in diploid and polyploid forms, but only diploids are currently used for interspecific hybridization purposes. Diploid forms of most Parthenium species are self-incompatible, but are compatible

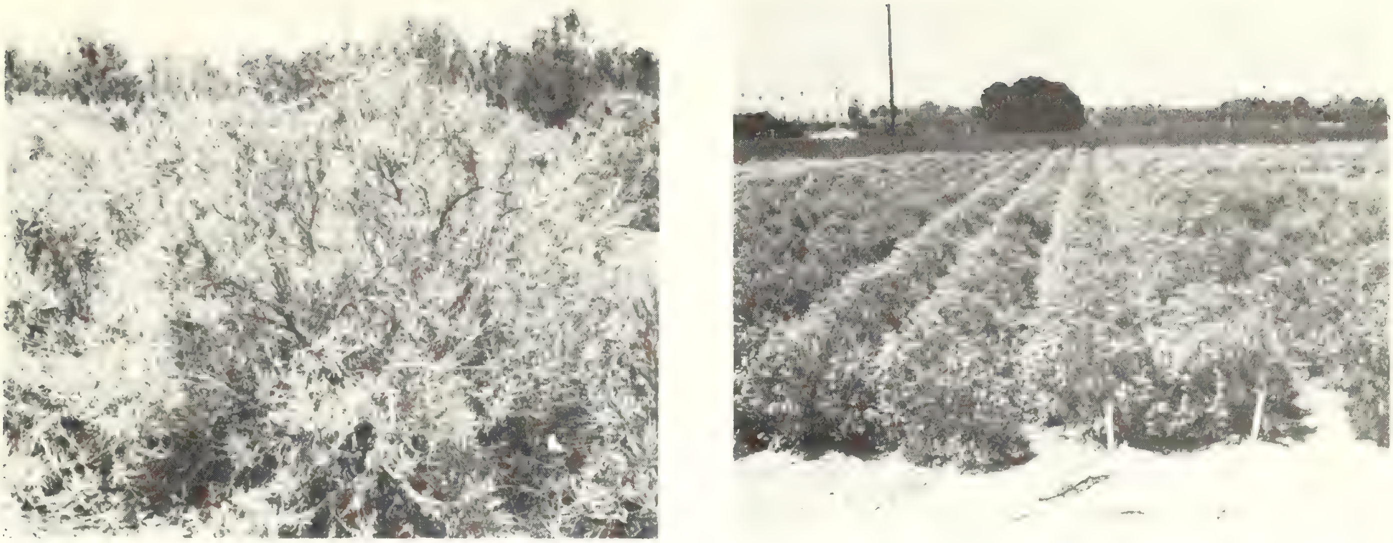

Figure 1.--Left: Close-up of a 4-year-old guayule plant reaching up to 1 m in height. Right: Various high-rubber guayule selections growing at UCR.

Table 7.--A list of *Parthenium* species that are used in the germplasm improvement program at UC Riverside. Some species exist in more than one type.

Taxon	Habit/Habitat	Breeding Need
SECTION PARTHENICHAETA		
P. tomentosum *P. fruticosum* *P. schottii*	Small deciduous trees, tropical, subtropical, thorn forests (500-1500 m)	Improve biomass and disease resistance
P. argentatum *P. incanum* *P. rollinsianum*	Densely pubescent shrubs, Chihuahuan Desert, primarily on limestone.	Improve cold tolerance and rubber
SECTION POLYPHYTUM		
P. alpinum *P. ligulatum*	Small perennial shrubs, montane (2500-3000 m), on gypsum outcrops.	Improve cold tolerance
SECTION PARTHENIASTRUM		
P. integrifolium *P. hispidum*	Perennial tuberous herbs, grassland prairies and temperature deciduous forests.	Improve cold tolerance, more water requirement
SECTION ARGYROCHAETA		
P. hysterophorus *P. confertum*	Annual and perennial herbs, temperature lowlands.	Adopt to annual habit

with other species. Emasculation is, therefore, not necessary. Interspecific hybridization is carried out under controlled conditions in the greenhouse, as well as in the open-pollination field plots. Rubber analysis and morphological investigations of new taxa are carried out routinely.

Preliminary rubber analysis of some *Parthenium* species and hybrids are provided in table 8. Figure 2 gives a view of some of these taxa in the field. These results clearly indicate that: (1) interspecific hybridization is possible between guayule and most other species, (2) F_1 hybrids have inherited much higher biomass than their guayule parents, (3) rubber contents of these hybrids are somewhat intermediate between the two parents, and (4) they have inherited high molecular weight rubber like their guayule parents. These trends are very important and it is expected that further germplasm improvement is possible through further crossing and backcrossing of these taxa. The ultimate objective is, of course, improvement in biomass and rubber quantity and quality in the newly developing taxa.

Table 8--Preliminary determinations of rubber contents in some *Parthenium* species and their F_1 hybrids. Values are based on the analysis of some 2- to 4-year-old plants growing at UCR field station.

Taxa	Rubber Quantity (%)	Approximate mol. wt.
P. argentatum	0.30 - 13.00	> 2,000,000
P. schottii	0.05 - 0.50	< 5,000
P. fruticosum	0.05 - 0.50	< 5,000
P. tomentosum	0.10 - 0.50	< 50,000
Hybrid A x S	2.00 - 3.00	> 1,000,000
Hybrid A x F	2.00 - 3.00	> 1,000,000
Hybrid A x T	1.00 - 2.50	> 1,000,000
P. incanum[1]	1.00 - 2.00	> 150,000
P. rollinsianum[1]	1.00 - 4.00	> 150,000
P. alpinum[1]	1.00 - 2.00	> 150,000
P. integrifolium	1.00 - 1.50	< 50,000

[1] Data courtesy of Jan West.

DISCUSSION AND CONCLUSIONS

It has been established without any doubt that natural rubber is an essential industrial and strategic commodity in the United States and other industrialized societies. It is also a biological fact that the tropical rubber tree *Hevea brasiliensis* cannot be grown in the U.S. and other countries with predominantly arid climates. It is, therefore, important that alternate sources of natural rubber should be explored in order to avoid economic and political crises in the future. The concept is not new and it was experimented in the past with varying degrees of success.

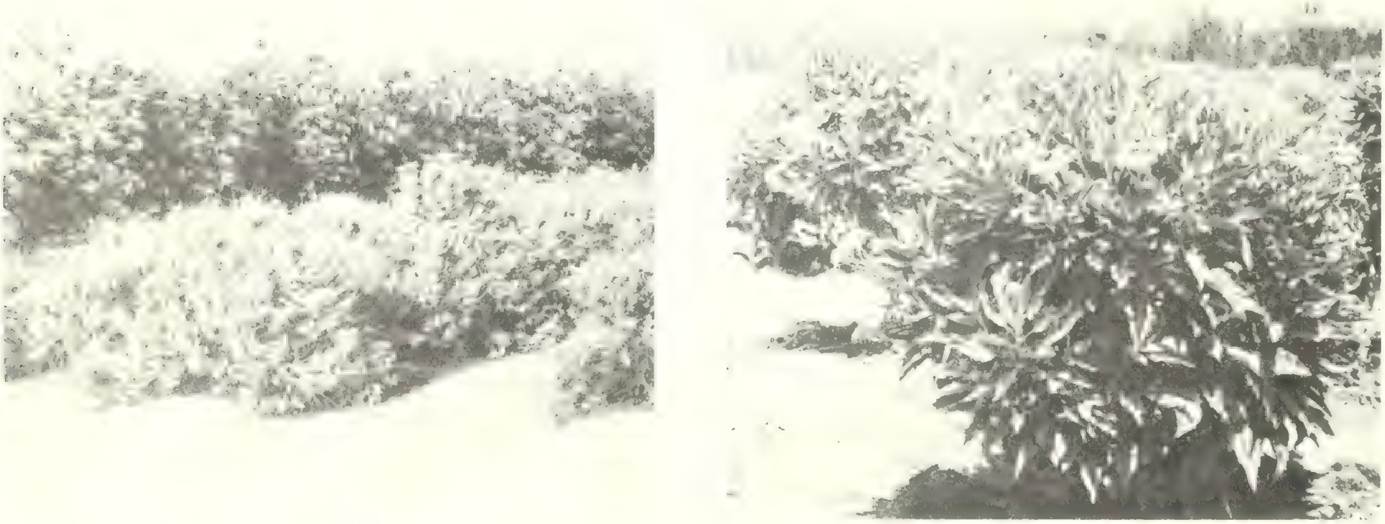

Figure 2.--Left: 4-year-old guayule plants growing in front of same age *Parthenium tomentosum* plants. Right: 2-year-old F_1 hybrid between guayule and *P. tomentosum*. It is already larger than the 4-year-old guayule parent.

In the beginning of the century, Africa stood second to South America in the amount of rubber supplied for world consumption. The continent reached its maximum in the year 1906 with shipments amounting to over 20,000 tons. Most rubber came from the wild species including Funtumia (F. elastica, especially), Landolphia, Chilandra, Carpodinus, Mscarenhasia, and others. Rubber production declined during the next few years due to indiscriminate harvesting and destructive collection practices. In America, a search also continued for finding good sources of natural rubber, but without lasting effects. The Central American rubber tree, Castilla elastica, was utilized as a rubber source since at least 1903, although historically it was used by the natives long before that. During the same period of time, many species of Jatropha, Pedilanthus, Plumeria, and Euphorbia, were experimented in Mexico and were found to contain rubber, but none were really exploited commercially. In the United States, species of Chryothamnus, Haplopappus, Asclepias, and some other plants were also tried with small successes, but without lasting results. The only plant that showed significant promise and continued to attract the attention of scientists and others is the guayule rubber plant that had its own share of ecological crises and mishandlings that were described earlier.

Two important lessons can be learned from this discussion: (1) guayule offers the best alternative to hevea, especially for countries in the arid and semiarid regions, and (2) natural plant resources are finite and cannot tolerate the pressures of indiscriminate harvesting and mismanagement.

In the United States, it is more or less accepted that guayule domestication and agronomic studies need to be done to commercialize guayule as a competitive crop. Although significant amounts of seed are available, the priority is to improve this seed through breeding programs in order to make it an economically feasible crop. In Mexico, on the other hand, the emphasis is on utilizing the native stands of guayule as raw material for industry. There are no exact estimates of the total shrub available in the wild. A system analysis provided by Anderson (1981) estimates the maximum sustainable yield from the guayule wild stands to be in the neighborhood of 2,700,000 tons. These and other investigators in Mexico and elsewhere believe that if these resources are once again utilized as raw material for the industry, they will be depleted within less than a decade. A proper reforestation and management program may, however, slow down the depletion process indefinitely.

From a genetic point of view, each guayule plant in nature is a unique combination of genes. Instead of using them as raw material, they can better be utilized in a systematic improvement program, and may result in the development of superior lines. These improved lines can later be utilized for reforestation or cultural operations. Establishment of germplasm banks and improvement centers in the native guayule areas can provide jobs as well as improved germplasm and raw material that can be used locally or shipped elsewhere as viable export commodities.

ACKNOWLEDGEMENTS

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Resumen.--Guayul (*Parthenium argentatum* Gray) es un hule con la potencial de producir una cosecha en areas aridas. Las problaciónes naturales y frágil ecológicamente, que fueron explotadas en pasado, necesitan de ser protegidas como recursos biológicamente valiosos, y no usadas como materia prima para industria. En UC Riverside, se han desarollado metodologías para el propio manejo y utilización de germen plasma del guayule, y para además mejoralo por selección y habridación. Progreso significativo se ha hecho en programas de domesticación y comercialización.

Manejo de Poblaciones Silvestres de Jojoba en Baja California[1]

Jorge I. Sepulveda B.[2]

Resumen.--Poblaciones silvestres de jojoba son un recurso economico importante para los habitatantes dentro la area de distribución. El uso de jojoba debida ser un base de invormación derivada de metodologías fuerte. Las poblaciones son un fuente de germen plasm que se puede usar en el futuro para la comercialización de las cosechas. Para establecer quías para usos, es necesario (1) tener un inventario de las poblaciones naturales y las arcas de distribución; (2) establecer areas protegidas de uso, para hacer observaciones sobre la fenología, y proveer protección contra factores adversos como ramoneo, incendios, etc; (3) seleccionar areas para reforestación por las propias agencias. La coordinación de activades sobre manejo por las agencias respectivas es importante para el futuro de el recurso.

INTRODUCCION

El nuevo enfoque que se le esta dando actualmente a las zonas áridas y semiáridas de México, considerandolas como un verdadero potencial en cuanto a las diferentes especies que lo componen, ha permitido que dia a dia, al traves de la luz de los estudios científicos, se haya ido ampliando el horizonte de su participacíon en los procesos productivos de la economía nacional. Son numerosas las especies tanto del desierto chihuahuense como en el sonorense que estan siendo aprovechadas y que de una u otra forma constituyen una fuente alterna de ingresos de las poblaciones rurales de estas regiones.

En el caso particular del desierto sonorense, indudablemente es la jojoba, cuyas caracteristicas, cualidades y usos son por todos conocidas.

En el presente trabajo se pretende conceptualizar la jojoba en el marco de su aprovechamiento y manejo en forma silvestre, con las bondades de sus beneficios y sus peligros asi como tambien, basado en las experiencias derivadas de traeajos de investigación, se establecen algunas perspectivas futuras para la jojoba en el ambito de su aprovechamiento y conservación: es decir, como un recurso renovable.

ANTECEDENTES

Con el objeto de establecer un marco de referencia para esta reunion, mencionaremos algunos conceptos basicos sobre la jojoba, que para el caso de este trabajo constituyen elementos de suma importancia para comprender la interrelacion que guardan los diversos factores que deberan tomarse en cuenta para establecer los criterios en su manejo y aprovechamiento.

HABITAT NATURAL

Distribucion

El origen de la jojoba, asi como su distribucion en tiempos remotos, no son claros aun, no obstante y debido a su habito de crecimiento y reproduccion, se infiere que esta especie tuvo su origen a lo largo de la costa del pacifico en un clima de tipo mediterraneo, es decir, en la region noroccidental de los estados de Baja California y California, en Estados Unidos.

La distribución actual de las poblaciones de jojoba son el resultado de una serie de factores bioticos y abioticos que la han confinado a la situación que guarda actualmente. Estos factores, por tener una participación determinante, se mencionan a continuación.

Orografia

La orografía es uno de los elementos que intervienen en la distribución de la especie, actuando algunas veces como verdaderas barreras, por su parte la fisiografía se encuentra muy relacionada con la presencia de poblaciones de jojoba.

En estudios realizados por diversas instituciones nacionales se constata una marcada preferencia en el habito de la jojoba a localizarse en ladera y lomerios, relacionado esto directamente a la acumulación de humedad y nutrientes.

El limite altitudinal en el que se encuentra la jojoba en México fluctua entre 5 m a 1000 msnm, correspondiendo este limite maximo a los pies de monte de las sierras de Juarez y San Pedro Martir en Baja California.

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[1] Ponencia presentada en la Reunión Sobre Manejo de Plantas en Zonas Aridas. Saltillo, Coahuila, México. Febrero 18-22, 1985.

[2] Biol., Jefe del Centro Experimental Forestal Ensenada, Baja California. México.

Suelos

La jojoba en su distribución prospera con muy variados tipos de suelos, aun cuando existe la evidencia de una marcada preferencia de esta especie con suelos de origen granitico con pedregosidad superficial que van de las arenosas, como en las dunas costeras, a las arcillo-arenosas, con drenajes de medios a rapidos, y con escasa materia organica y nitrogeno.

Clima

Uno de los factores mas importantes y determinantes en la vida de la planta de jojoba y en el aspecto económico desde el punto de vista del interes del hombre, sin duda es el clima. Si bien es cierto que los factores anteriormente mencionados son importantes para la presencia de las poblaciones silvestres de jojoba en su area de distribución, es el clima quien determina de manera definitiva la producción de la semilla, la cual constituye basicamente el interes por esta especie. precipitación, temperatura y distribución de esta en diferentes epocas del año determinan el aumento disminución de la producción de semilla, limitadas estas evidentemente por los factores genotipicos de la especie.

Como se habia mencionado con anterioridad, la especie prospera mejor en un clima de tipo mediterraneo, es decir, con un porcentaje mayor de lluvia de invierno que de verano y una distribucion que vaya de noviembre a abril esta característica climática corresponde a la porcion noroccidental del estado de Baja California y coincidentemente es la region con mayor densidad en poblaciones y con una producción mayor que la del resto del área de distribución en los estados de Baja California sur y Sonora, los cuales poseen regimenes de lluvia de verano, siendo estos ultimos menos efectivos debido a las altas temperaturas, humedad relativa baja y gran evaporacion.

La cantidad de precipitacion, aun cuando es importante, se considera que su distribución es el factor determinante de una buena produccion, es preferible una baja precipitacion distribuida convenientmente, que una grande torrencial y efimera.

En terminos generales, la jojoba tolera precipitaciones en un rango que va de los 100 a los 500 mm.

La temperatura junto con la precipitacion se interrelacionan para conformar las diferentes condiciones climáticas en el área de distribución de la jojoba.

En terminos de la especie, esta tolera altas temperaturas hasta de 50°C. En cambio, las bajas temperaturas entre los 0° y -60°C pueden tener efectos negativos importantes en la floracion y en general en la fisiología de la planta.

Vegetación

De acuerdo a shreev en la demarcacion de las áreas fitogeográficas del desierto sonorense, la jojoba se localiza en todas las regiones señaladas por el autor, lo que indica la gran adaptabilidad de la especie para asociarse a las diversas comunidades vegetales que constituyen ese desierto.

Existe algo importante a destacar en relación a la vegetación y, de acuerdo a estudios realizados, algunas plantas actuan como especies protectoras de la jojoba en su etapa juvenil. Por lo tanto, para el manejo de poblaciones silvestres, este hecho constituye un criterio fundamental a emplear.

Fenología

Quiza uno de los procesos de mayor interes económico es lo referente a las etapas fenológicas de la especie que determinara en el proceso de formación de la semilla.

La maduración del fruto varía segun el área que se trate. En el estado de Baja California, la producción de semilla se efectua en los meses de junio-julio, mientras que en Baja California sur la maduración del fruto tiene lugar en los meses de marzo-abril. Las diferencias anteriores se encuentran intimamente relacionadas principalemnte a la estacionalidad de las lluvias en las diferentes areas, como ya se había anotado anteriormente.

Estas diferencias en la maduracion del fruto en ocasiones acarrea problemas en el buen manejo de las poblaciones que repercuten tanto en la condición de la planta como en la calidad del producto que se obtiene. Esta situación se complica aún mas cuando en la misma planta la maduracion del fruto no es uniforme, observandose diferentes estadios logicos simultaneamente.

DIAGNOSTICO DEL APROVCHAMIENTO Y MANEJO DE LAS POBLACIONES DE JOJOBA

El aprovechamiento de los rodales silvestres ha sido una actividad realizada para diferentes propositos desde hace cientos de años por los antiguos pobladores del desierto sonorense: no obstante la presión que ejercian estos aprovechamientos, era minima en cuantia y en el impacto indirecto que ocasionaba lo anterior, debido principalmente al empleo que se le daba, a las poblaciones humanas relativamente bajas y al no madismo de las tribus, que en cierta forma evitaba una sobrexplotacion en una area determinada.

En terminos generales se puede decir que el hombre vivía en equilibrio con esta especie.

Con el devenir de los tiempos, en aumento de la población, en desarrollo tecnológico en la agricultura y la introducción del ganado caprino y bovino y la apertura de vias de comunicacion han ocasionado un impacto considerable a las poblaciones silvestres de jojoba.

En el año 1954 se inicio, aunque en Baja escala, el aprovechamiento de la jojoba silvestre, al instalarse en la empresa laboratorios jojoba, la semilla utilizada provenia de Sonora y Baja California sur principalmente. Fue hasta el año 1972, a raíz de la primera reunion internacional sobre jojoba, cuando se disparo el interes sobre la especie. Una presion gradual pero creciente se fue aplicando a las poblaciones silvestres en toda el area de su distribucion natural y que evolucionaria de la fase experimental hasta los sistemas actuales de aprovechamiento.

¿Como se han manejado las poblaciones de jojoba y cuales son los metodos que se han aplicado?

Debido a que la jojoba es apetecida por el ganado tanto bovino como caprino, las poblaciones silvestres son afectadas fuertemente por el ramoneo de estas especies, asi es que unos de los primeros trabajos que se han realizado para mejorar su condición es la protección de los rodales con cercos de alambre de puas. De acuerdo a datos obtenidos por diversas instituciones, se calcula un total aproximado de 8,000 ha que se encuentran protegidas de la acción del ganado.

Desmontes

Dentro del manejo que se les ha dado a las poblaciones silvestres se incluyen los desmontes. Que van de las selectivas, o sea las que elimina solo aquellas especies que en una o otra forma dificultan el aprovechamiento, a los desmontes totales, dejando unicamente la jojoba. Los desmontes por lo general son manuales e incluyen la quema de las especies eliminadas.

Labores Culturales

Las labores culturales que actualmente se aplican a los rodales son la formacion de microcuencas para la captacion de aguas de escurrimiento, encontrandose de varios tipos: cajetes, herraduras, zonjas, etc., y de acuerdo al terreno esto se hace en forma manual o con maquinaria.

Tambien dentro de las labores culturales se usan las curvas a nivel.

Podas

Otras labores que se han aplicado a las poblaciones, aunque por su costo no se ha extendido, son las podas de estimulo y de formación.

Recoleccion de Semilla

Una de las actividades mas importantes dentro del manejo de las poblaciones son las refererentes a la recolección del fruto, y es en esta etapa en donde se conjugan los aspectos economicos y de conservacion.

Si se parte de la base de la jojoba constituye un elemento de un sistema que involucra una gran cantidad de interacciones tanto bióticas como abióticas, su manejo debera cimentarse sobre estudios ecologicos.

En el caso particular de la semilla, se estima que de un total que cae al suelo, un 95 por ciento es depredado por roedores, existiendo de un 2 a un 5 por ciento que tiene posibilidades de llegar a estapa de plantula.

Debido a este indice tan alto de depredación, la recolección del fruto se hace cuando la capsulacion no se ha desprendido de la planta. Este hacho hace que la recolección del fruto se realice en un tiempo en el cual la maduracion de la semilla no se completa totalmente, lo que aunado a que la fructificacion no es uniforme en la misma planta ocasiona que la recolección se haga indiscriminadamente en frutos con diferentes etapas de maduración.

Reforestacion

Dentro de los trabajos de reforestación que se han realizado en poblaciones silvestres de jojoba a lo largo de la peninsula de Baja California, destacan los de coteper (antes coplamar), entre los años de 1980-1984 se calcula que se realizaron reforestaciones en uños 3000 has. aproximadamente. Desafortunadamente por diversos problemas tecnicos y economicos estas actividades si bien no se han suspendido, estas han disminuido en forma notable.

Los trabajos de reforestación realizados implicaban la recolección de fruto, producción de planta y plantación en las areas cubiertas por jojoba o zonas aledañas a las misma. Las actividades de reforestación ademas de tener su efecto de conservación del recurso tambien mantuvo un importante repercusión social, como ejemplo de elloq se puede emencionar que, en el estado de Baja California se generaron por este concepto entre el periodo de 1980-1982 un total de 228,000 jornales.

SITUACION ACTUAL DEL MANEJO DE POBLACION SILVESTRE DE JOJOBA

Se considera actualmente que para poder tener un buen manejo de poblaciones de jojoba se deberan involucrar aspectos que van desde la organización de productores, aprovechamiento, comercialización e industrialización de la cera liquida.

La falta de conocimiento, tanto de autoridades como de poseedores del recurso ocacionaron que, hasta el año de 1978 el aprovechamiento y manejo de las poblaciones de jojoba se realizara en forma desordenada propiciandose una serie de actividades que asentuaban contra el recurso.

En la actualidad se han obtenido algunos logros con la aplicación de diversas normas de aprovechamiento y conservación que repercuten en obtener un manejo mas adecuado de las poblaciones de jojoba, a continuación y a manera de ejemplificar lo enterior se expondra los procedimientos que se siguen actualmente en el estado de Baja California sobre el particular.

Zonificación de áreas productoras en base a estudios de maduración de la semilla (Mapa 2), aun cuando existen variaciones importantes en cuanto a la maderación de la semilla en las diversas areas de distribución provocados por factores climaticos principalmente, la experiencia ha demostrado que en terminos generales existe un gradiente de maduración de la semilla de jojoba en el estado de Baja California que se inicia en el extremo sur de la entidad y termina en la porcion norte del mismo, no obstante cada año se requiere realizar inspecciones que determinen el estado fenológico que guardan cada zona en particular, para el efecto se han estado establecido sitios parmanentes de observación fenológica y dasométrica. La zonificación en este último caso ademas de los aspectos climaticos se han seleccionado en base a criterios de tipos de vegetacion, suelos, productividad y de importancia social, de tal forma que las zonas son representativas de la mayoria de la produccion de semilla de jojoba en el estado de Baja California.

Los datos obtenidos sirven de base para programar y aplicar el estudio dasonomico que prevee la ley forestal para cualquier aprovechamiento de este recurso.

El estudio dasonomico clasico, encuentra una variación en la especie de jojoba y esta es debido basicamente a que año con año deberan realizarse muestreos que permitan evaluar la producción de semilla de jojoba en un área determinada.

Para la obtencion de la producción se realiza un premuestreo que trasferido a la formula de tamaño de muestra nos indica la cantidad de sitios que se requieran muestrear en cada sitio se levantan diversos datos que se presentan en los cuadros uno y dos.

Como se ha de observar la metodología que se esta aplicando actualmente quiza no cumpla con los requisitos necesarios para la obtención de una información mas formal, no obstante los beneficios colaterales que se han obrenido como son el de establecer un vinculo de comunicación entre poseedores del recurso, autoridades y empresarios que comercializan e industrializan la cera liquida de jojoba, ha permitido subsecuentemente una mejor concientización sobre el manejo y aprovechamiento de las poblaciones silvestres de jojoba en la peninsula de Baja California.

Finalmente y a manera de recomendación, solicitamos se revitalice el comite coordinador de normas y estudies para la preservación y fomento de la jojoba, el cual conformaba una serie de elementos que permitian normar los aspectos técnicos y legales a fin de hacer congruente un programa nacional del aprovechamiento de la jojoba.

CONCLUSIONES Y RECOMENDACIONES

En base a los criterios expuestos se establece que las poblaciones silvestres de jojoba son una fuente alterna importante de recursos economicos de los Grupos humanos que habitan en su área de distribución.

-Que su aprovechamiento debera estar basado en información derivada de metodologías y practicas adecuadas para su uso persistente.

-Que es fuente potencial para la obtención de germoplasma para apoyar las futuras plantacioner comerciales.

-Que para establecer los criterios de aprovechamiento se requieran los siguientes elementos:

1. Inventario de las poblaciones naturales en el area de su distribución.
2. Zonificacion ecologica de los diferentes rodales para establecer sitios permanentes de observación fenológica.
3. Protección de las poblaciones a factores adversos como: ramoneo, plagas, enfermedades e incendios.
4. Selección, bajo criterios ecológicos, de las zonas de reforestación que llevan a cabo diversas instituciones para que se garantice el éxito de la misma.

-Finalmente, que se propicie una coordinación interinstitucional adecuada para el optimo manejo y aprovechamiento de este importante recurso forestal.

Abstract.--Wild populations of jojoba are a source of germplasm to be used in commercialization of future crops. In order to establish use guidelines it is necessary to; (1) have an inventory of natural populations and reas of distribution, (2) establish protected sites for making phenological observations and provide protection from adverse factors such as grazing, fire, etc., (3) select areas for reforestation by appropriate agencies. Coordination management activities by respective agencies is vital for the future of the resource.

Estimating Production and Utilization of Jojoba[1]

Bruce A. Roundy, George B. Ruyle and Jane Ard[2]

Abstract.--Twig weights of jojoba (Simmondsia chinensis) from three sites in southern Arizona were highly correlated with the square of twig internode diameter. Diameter measurements can be used to estimate the production of this important browse and its utilization by livestock and wildlife. Utilization estimates based on percentage of twigs browsed may be inaccurate.

INTRODUCTION

Jojoba (Simmondsia chinensis) is a drought-tolerant long-lived evergreen shrub of the Sonoran desert in northwestern Mexico and the southwestern United States. It grows best on well-drained, well-aerated, coarse soils associated with desert foothills and washes from 600 to 1200 m (Gentry 1958). The high content and desirable properties of wax esters in jojoba seed (Scarlett 1978) have led to extensive research on the chemistry, use and cultivation of this desert shrub (Elias-Cesnik 1982). But jojoba is also the best browse species for wildlife and livestock within its range (Kearney and Peebles 1964). Jojoba has historically been used by goats, sheep and cattle (Mills and Foster 1982) and provides food for rodents and birds (Gentry 1958, Sherbrooke 1976, Thomson 1976, Martin et al. 1951), javelina (Pecari tajaco) (Knipe 1956), desert bighorn sheep (Ovis canadensis) (Russo 1956), and mule deer (Odocoileus heminous) (Judd 1962, McCulloch and Urness 1973, Urness et al. 1977). Yet, little is known about the proper utilization and management of jojoba as a forage (Mills and Foster 1982). Observations are that jojoba is grazing tolerant (Judd 1962) but may have reduced seed production (Gentry 1958), reduced growth (Mills and Foster 1982) and reduced survival (Judd 1962) with heavy grazing. However, the impacts of grazing on jojoba have not been quantified (Mills and Foster 1982) so management guidelines used are those followed for other shrubs (e.g. Garrison 1971), including limits of 40% utilization under continuous grazing and 50% utilization under a rest rotation grazing system (U.S.D.A. Forest Service 1979). Utilization is generally estimated by determining the percentage of current year's twigs that have been browsed (U.S.D.A. Forest Service 1979). This method may overestimate actual weight utilization, especially where use is high (Stickney 1966, Jensen and Scotter 1977, Ruyle et al. 1983). A more accurate but more tedious method of estimating utilization is that of using least squares regression analysis to determine the relationship between twig weight and twig length or diameter (Rutherford 1979). Diameters or lengths of browsed and unbrowsed current year's twigs can than be measured to estimate the weight left and weight removed to calculate utilization. The prupose of this research is to examine methods of estimating jojoba utilization. Specific objectives include: (1) to compare the relationship of stem diameter to twig weight components of jojoba growing on different sites, (2) to determine the relationship of percent browsed twigs to percent weight removed by grazing, and (3) to determine the effects of different grazing intensities on distribution of leaves and twigs.

METHODS

Three sites were selected for initial jojoba sampling to develop diameter-weight relationships. The sites were located on the eastern slope of the Tucson Mountains, the southern foothills of the Santa Catalina Mountains, and in the area of the Horrell exclosure on the northern foothills of the Mazatzal Mountains south of Roosevelt Lake, all in southern Arizona. Associated soils are gravelly sandy clay loams and principle associated vegetation includes Franseria dumosa, Larrea tridentata and Acacia constricta at the Tucson and Santa Catalina sites, Encilia farinosa at the Santa Catalina site and Cercidium microphyllum, Lycium pallidum, and Larrea tridentata at the Roosevelt site in addition to jojoba.

During the summer of 1984, large branches were sampled from 20 ungrazed shrubs at each of the three sites. To determine the relationship between fresh and oven-dried twig diameter, the mid-internode diameter of 150 twigs ranging in water content from 9 to 52% was measured before and after drying in an oven at 70°C for 24 hours. Thereafter, all samples were oven-dried and minimum mid-internode diameter and leaf, stem and total weight measured. Measurements for branches from each site included a minimum of 20 branches with diameters 3.05 to 5 mm and a minimum of 141 twigs with diameters ≤ 3 mm. Leaf widths, lengths and weight of leaf pairs were also recorded. Oven-dried weight parameters were regressed on oven-dried mid-internode diameter. Regression slopes and intercepts for the different sites were statistically compared ($p \leq 0.05$) using methods described by Snedecor and Cochran (1971).

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Additionally, large branches on two moderately grazed areas near the Roosevelt site were sampled to determine the relationship between percent of twigs browsed and percent weight removed by grazing. The Horrell area is grazed year long and the Burnt Corral area was grazed four months prior to sampling. At each area three branches having a minimum of 10 twigs of current year's growth were sampled from each of 20 shrubs. Branches were oven-dried, numbers of grazed and ungrazed twigs were counted, and twig diameters were measured at the point of grazing for current and previous years' twigs. All remaining current and previous years' twigs with a mid-internode diameter ≤ 3 mm were weighed. Weight removed by grazing was estimated using previously developed regression equations and divided by total weight to give an estimate of percent utilization by weight. Percent utilization by weight was regressed on percent browsed twigs and utilization estimates by number of browsed twigs and by diameter measurements were statistically compared ($p \leq 0.05$) in a nested one-way analysis of variance. All twig diameters were measured to the nearest 0.05 mm with a dial caliper and weights were measured to the nearest mg.

To estimate the effects of grazing on shrub leaf and twig distribution within the canopy, main branches were clipped from 20 shrubs having received light, moderate, and heavy browsing from cattle. The shrubs were at the Roosevelt site and were associated with different distances from water. For each main branch, number of leaf pairs and current and previous years' twigs were counted in 5-cm cross sections perpendicular to the main branch. Shrub components for the different grazing treatments were compared by analysis of variance and Duncan's multiple range test.

RESULTS AND DISCUSSION

Twig weight components of jojoba were most highly correlated with the square of oven-dried mid-internode diameter (table 1, fig. 1). Coefficients of determination (r^2) were higher when twig diameters between 3 and 5 mm were included in the analyses than when only twig diameters ≤ 3 mm were analyzed. Because of the higher sample size, the coefficients of determination are a better indication of twig weight variability with respect to mid-internode diameter for the smaller diameter twigs than the larger diameter twigs. It was observed that twigs greater than 3 mm diameter

Table 1. -- Intercepts(a), regression coefficients(b), coefficients of determination (r^2), and standard errors of estimate (S.E.E.) for jojoba twigs on three sites in southern Arizona of the form: $y = a + bx^2$, where y is oven-dried weight(g) and x is oven-dried mid-internode stem diameter (mm).

		Leaf weight				Stem weight				Total weight			
Site	Number observations	a*	b*	r^2	S.E E.	a	b	r^2	S.E.E.	a	b	r^2	S.E.E.
					Stem diameter ≤ 5 mm								
Roosevelt	180	-0.42b	0.48a	0.85	0.84	-0.29a	0.25a	0.91	0.34	-0.72b	0.72a	0.89	1.09
Tucson	162	-0.47a	0.42b	0.90	0.61	-0.36b	0.24a	0.92	0.31	-0.83a	0.66b	0.92	0.88
Santa Catalina	178	-0.28a	0.34c	0.85	0.63	-0.30b	0.21b	0.92	0.28	-0.59a	0.55c	0.90	0.82
Sites combined	510	-0.43	0.42	0.85	0.75	-0.33	0.24	0.91	0.31	-0.75	0.66	0.89	0.99
					Stem diameter ≤ 3 mm								
Roosevelt	153	-0.12b	0.30a	0.82	0.19	-0.07a	0.12a	0.56	0.14	-0.17a	0.41a	0.81	0.27
Tucson	141	-0.08a	0.24b	0.84	0.20	-0.12a	0.13a	0.73	0.14	-0.20b	0.37a	0.83	0.32
Santa Catalina	157	-0.20a	0.28a	0.83	0.25	-0.13a	0.13a	0.82	0.12	-0.32b	0.41a	0.85	0.33
Sites combined	451	-0.12	0.27	0.81	0.22	-0.10	0.13	0.73	0.14	-0.22	0.39	0.83	0.31

* Intercepts and regression coefficients for different sites followed by the same letter are not significant different ($p \leq 0.05$) according to the elevation and slope tests of Snedecor and Cochran (1971).

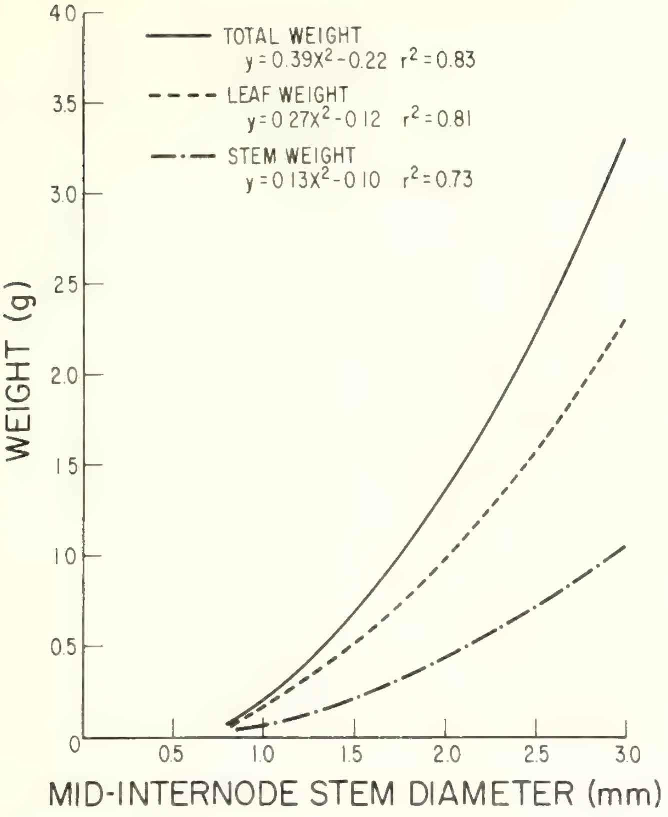

Figure 1.--Leaf, stem and total oven-dried weight of jojoba twigs in relation to oven-dried mid-internode diameter for twigs with diameter $\leq$ 3 mm.

were rarely grazed so the regressions for the smaller diameter twigs should be more useful than those including the larger diameter branches in estimating utilization. Regressions for the larger diameter branches indicate the potential of diameter-mass equations for estimating total biomass of jojoba.

Regression coefficients and intercepts had greater variation among sites when large diameters were included in the regression analysis than when only smaller diameters were analyzed (table 1). Regression coefficients and intercepts of equations for estimating leaf weights varied more among sites than those estimating stem weights from small twig diameters.

Table 2.--Mean weights, lengths and widths of jojoba leaf pairs on three sites in southern Arizona

Site	No. of samples	Leaf pair weight (mg)	Leaf length (mm)	Leaf width (mm)
Roosevelt	153	159.7a	23.8b	9.5a
Tucson	141	137.2a	23.0b	9.0a
Santa Catalina	157	146.7a	26.6a	10.0a

Means in columns followed by the same letter have overlapping 95% confidence intervals.

Leaf weight accounted for an average of 73% of the total twig weight for small diameter twigs and was similar for all three sites. Mean leaf weights and size were also similar for all three sites (table 2). Estimates of total twig weight for small diameter twigs varied less than 0.3g among the three sites sampled. There was a high correlation ($r^2 = 0.99$) between fresh (x) and oven-dried mid-internode diameter (y) where:

$$y(\text{mm}) = 0.922x\ (\text{mm}) - 0.142$$

This high correlation indicates that twig weight of jojoba can be estimated from measurements taken on the plant or from oven-dried samples. Equations for estimating total weight will be most useful in calculating jojoba utilization by cattle since they tend to browse twigs and leaves of jojoba nonselectively. The coefficients of determination of twig diameter and weight are not quite as high for jojoba on these sites as has been found for many large-leafed eastern shrubs (Telfer 1969) or for western shrubs such as deerbrush (Ceonothus integerrimus) ($r^2 = 0.97$, Bartolome and Kosco 1982), snowberry (Symphoricarpos oreophilus) ($r^2 = 0.90$, Ruyle et al. 1983), blackbrush ($r^2 = 0.94$, Provenza and Urness 1981), and bitterbrush (Purshia tridentata) ($r^2 = 0.89$, Basile and Hutchings 1966). However, low standard errors of estimate (table 1) indicate diameter measurements can give precise estimates of jojoba twig weight. Utilization percentages can easily be calculated by measuring maximum diameter of browsed and unbrowsed current year's twigs to determine total yield and by measuring diameters of browsed twigs at the point of browsing to determine weight removed by browsing. These measurements should be taken at the end of the grazing period before regrowth occurs. In developing and using diameter-weight relationships of jojoba it should be remembered that leaf fall may occur with summer drought (Gentry 1958). Also, flushes of vegetative growth associated with significant precipitation occur in the spring and summer (Haase 1976). Jojoba utilization should be measured after significant growth and use periods.

Percentage of number of twigs browsed tended to be lower than percent utilization by weight for current year's twigs, but was slightly higher than weight utilization for total twigs on two moderately grazed areas (fig. 2). Percent browsed twigs would tend to underestimate weight utilization of current year's twigs and overestimate utilization of total twigs, especially at high utilization levels. There was high variation in weight utilization among branches with similar percentages of twigs browsed. However, mean percent utilization by weight and by numbers of browsed stems was generally statistically similar for both areas (table 3). A plot of the variance of weight utilization in relation to sample size indicates that for these moderately-grazed shrubs, at least two branch samples from each of at least 18 shrubs, with 10 or more twigs per branch, were needed to obtain a good estimate of utilization.

One major problem in estimating utilization of jojoba is that of determining how much current

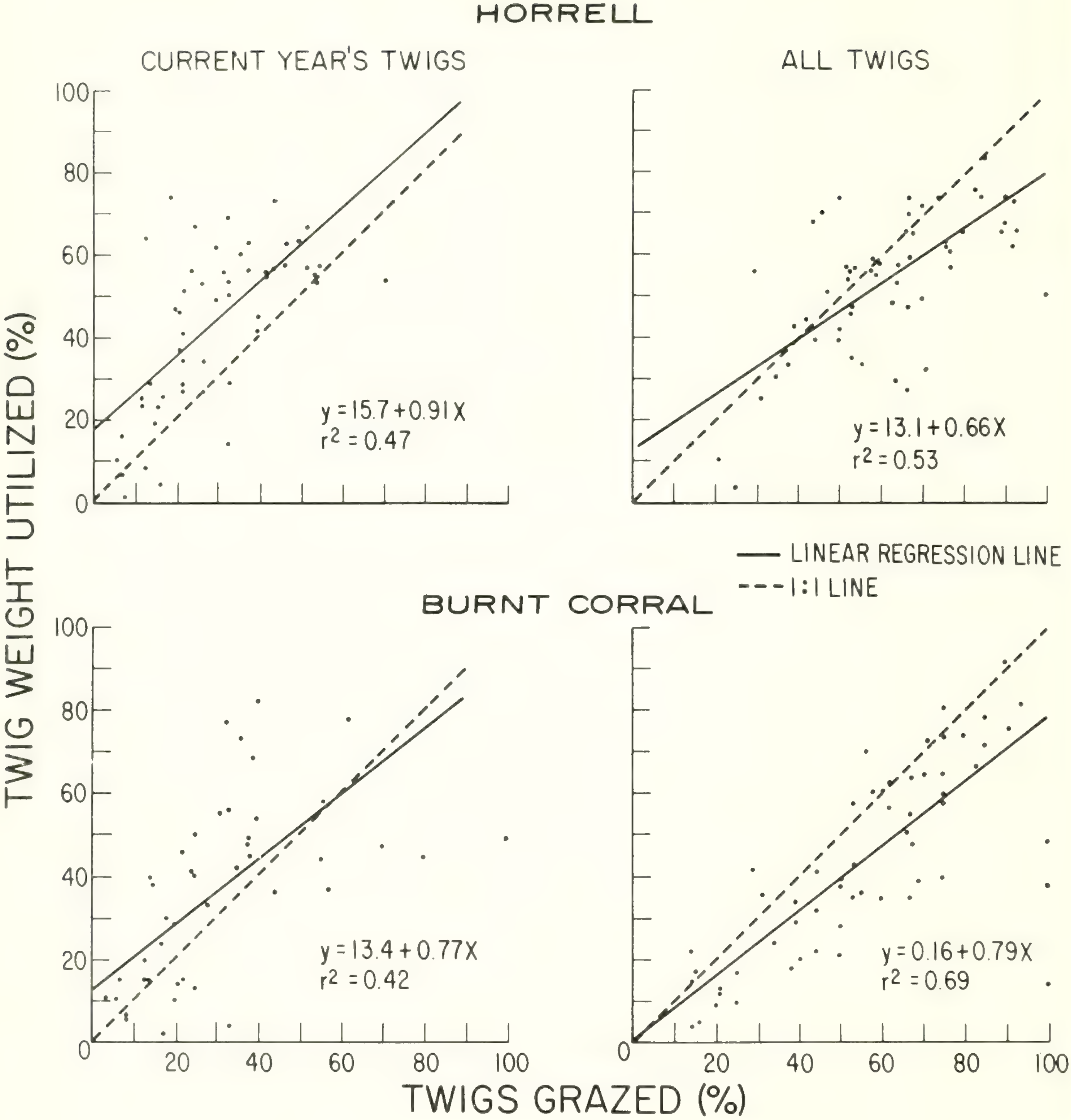

Figure 2.--Percent weight of jojoba utilized in relation to percent twigs browsed for moderately-grazed shrubs at two areas in southern Arizona.

Table 3.--Percent twigs browsed and percent weight utilized for moderately-grazed jojoba on two areas in southern Arizona.

	Current year's twigs		All twigs with diameter <3 mm	
Utilization estimate	Horrell	Burnt Corral	Horrell	Burnt Corral
Twigs browsed (%)	27.2b	23.8a	59.1a	54.8a
Weight utilized (%)	39.a	29.4a	52.0a	42.7a

Means in columns followed by the same letter are not significantly different ($p \leq 0.05$).

year's growth has actually been removed by grazing animals during a grazing period when some previous year's growth has been taken. It is not possible to determine how much current year's growth is associated with previous years' stems that have been removed in the current year. It was observed that cattle may graze previous years' twigs before all current year's twigs have been browsed.

Intensity of grazing affects the distribution of leaves and twigs with respect to depth in the jojoba shrub canopy (fig. 3). Most leaves and twigs are concentrated between 10 to 30 cm deep in the canopy. However, lightly grazed shrubs (< 10% utilization) had leaves and twigs more evenly distributed in the canopy than heavily-grazed (≥ 80% utilization) and moderately-grazed (40-50% utilization) shrubs. As grazing intensity increases, twigs and leaves are concentrated at a shallower depth in the shrub canopy. Peak numbers of twigs and leaves occurred at depths of 30, 25 and 20-cm into the canopy for lightly, moderately, and heavily-grazed shrubs, respectively. Although moderately and heavily-grazed shrubs were smaller in size, they had as many or more current and previous year's twigs and leaf pairs per branch as did lightly-grazed shrubs (table 4). Browsing jojoba evidently stimulates twig growth from lateral dormant buds as occurs with many other shrubs (Garrison 1971) and results in a hedged appearance. Mills and Foster (1982) have cited observations that jojoba is not only tolerant of pruning but that pruning stimulates vegetative growth. The greater leaf pair numbers of moderately than lightly-grazed shrubs in this study indicate that new growth stimulated by twig removal compensates for loss of twigs as suggested by Mills and Foster (1982). Browsing does not necessarily reduce photosynthetic capacity but may actually increase it by stimulating twig and leaf production on a per branch basis. Moderate grazing resulted in highest photosynthetic biomass per branch as indicated by highest numbers of leaf pairs compared to lightly and heavily-grazed shrubs.

Since successive weather conditions that produce high seed germination and seedling survival are rare (Mills and Foster 1982) continuing seed production over many years is necessary to ensure stand renewal and stability of jojoba. Thus, the effects of browsing on jojoba seed production is of concern. Gentry (1958) cites examples of high seed production of shrubs that were pruned and irrigated and also lack of fruit development in wild plants severely browsed by cattle. Ruyle and Roundy (1985) found jojoba shrubs continuously grazed for at least 30 years were smaller in size than ungrazed shrubs and that jojoba cover was less but shrub density similar for adjacent grazed and ungrazed stands. Jojoba is thought to have a long life span (Gentry 1958) and, theoretically, each female plant would only have to produce two successful seedlings over its lifetime to maintain a stable population (Mills and Foster 1982). Because of jojoba's longevity and the infrequency of weather conditions for high seedling survival, the effects of reduced seed production or seed removal on jojoba stand renewal is uncertain and can only be determined

Table 4.--Total numbers of stems and leaf pairs per branch for jojoba under different grazing intensities.

			Stems		
Grazing Intensity	Weight utilized (%)	Leaf pairs	Current years (Number/Branch)	Previous years	Total
Light	≤10	95.2b	30.4a	19.0b	48.3b
Moderate	40-50	146.7a	37.9a	27.6a	65.6a
Heavy	≤80	92.7b	29.4a	28.9a	58.9ab

Means in columns followed by the same letter are not significantly different ($p \leq 0.05$) by Duncan's multiple range test.

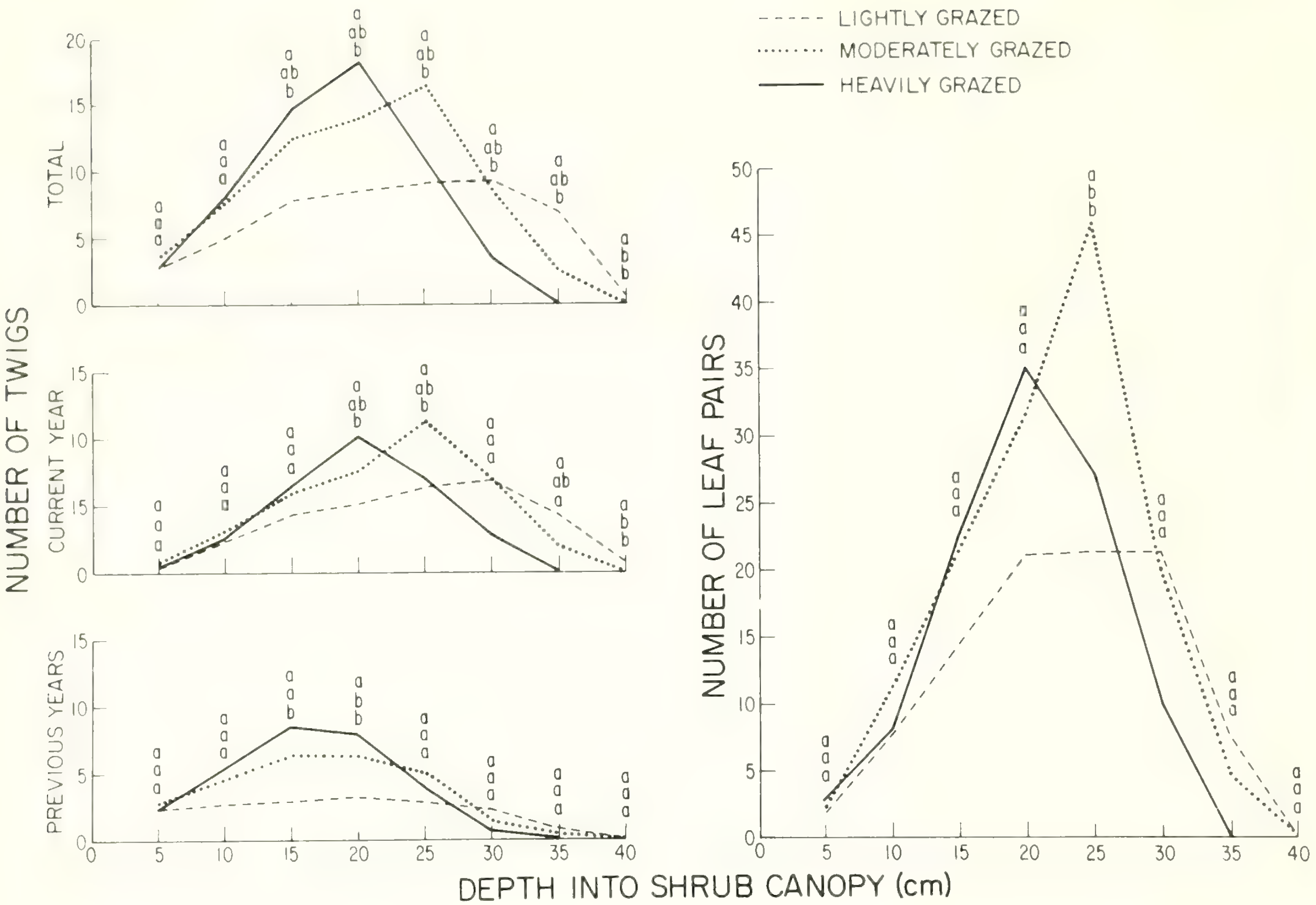

Figure 3.--Numbers of stems and leaf pairs in relation to depth into the canopy for lightly, moderately, and heavily-grazed jojoba in southern Arizona. Letters above apply to points below in order and any points having the same letter are not significantly different ($p \leq 0.05$) at that depth by Duncan's multiple range test.

in long-term studies (Mills and Foster 1982). Given the high tolerance of jojoba to grazing and its ability to maintain high amounts of photosynthetic tissue when grazed, practical guidelines for its management might be better concerned with monitoring shrub size than the more time-consuming process of estimating utilization. Maximum and minimum crown diameter and height of marked shrubs could be measured on a yearly basis. A gradual increase in shrub size would indicate that the shrub has a positive energy budget and is able to maintain itself and expand under the present management. Decreases in shrub size not associated with die-back during very dry periods (Gentry 1958) would indicate overgrazing.

More definitive guidelines for grazing management will be available with continued research on jojoba response to defoliation. Methods of estimating yield and utilization presented in this study will be useful in conducting this research and in estimating utilization more accurately than by counting browsed twigs. In the meantime, management based on maintaining or gradually increasing shrub size relative to the potential for a given site may be an appropriate alternative to managing for a given level of utilization.

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Resumen.--Pesos de ramitas de jojoba (Simmondsia chinensis) de tres sitios en Arizona sur fueron correlaciónados por alta medida con la cuadra del diámetro de internodio de ramitas. Medidas de diámetro se pueden usar para estimar la producción de este arbusto importante y su utilización por ganaderia y fauna sylvestre. Estimas de utilización apoyo del el porcentaje de ramitas ramoneadas puede se inexacto.

El Cultivo de la Jojoba en el Noroeste de Mexico [1]

Ricardo Ramonet Rascon[2]

Resumen.--Investigaciónes antepasados han indicado que hay un gran potencial para la producción y comercialización de jojoba. Estudios ecológicos han puesto su énfasis sobre la technologia para producción. Programas de investigaciónes de CIANO buscan a descubrir clones de jojoba que tengan características favorable para producción y su propagación.

INTRODUCCION

Son pocas las especies silvestres que en los últimos quince años hayan tenido tanta promoción e investigación para lograr su domesticación y aprovechamiento del recurso silvestre, como ha sucedido con la jojoba (Simmondsia chinensis). Esta especie silvestre del Desierto Sonorense se distribuye en los esta dos de Sonora y Baja California en México y Arizona y California en Estados Unidos. Sus características principales por las que ha promovido tanto interés, son su capacidad de desarrollo y sobrevivir Bajo condiciones prolongadas de sequía, y por las características tan peculiares de la cera líquida que se acumula en sus semillas.

La jojoba es una planta dioica, su raíz es pibotante y tiene un crecimiento rápido durante la germinación; alcanza a profundizar más de 4 m en condiciones favorables. La planta está formada por varias ramas que nacen de la corona de la raíz. Es un arbusto siempre verde de formas variadas, tipificándose en erectas, estéricas y rastreras. Las hojas son coriaceas, de forma oblonga y dispuestas en pares. Las flores estaminadas son por lo general solitarias que crecen en las axilas de hojas en crecimiento anual, al igual que las flores pistiladas, sólo que éstas se presentan en racimos.

El fruto es una cápsula generalmente dehicente, y en ésta se desarrollan de una a tres semillas que contienen en los cotiledones de 30 a 60 por ciento de cera líquida, fácilmente extractable con prensas de uso convencional.

Usos de la Cera de Jojoba

A partir de diciembre de 1970, fecha en que entró en efecto la prohibición de importaciones de aceite de ballena a los Estados Unidos, se inició investigación de posibles sustitutos (Gisser, 1975). Hasta esta fecha, Estados Unidos importó un promedio anual de 18 000 toneladas de aceite de ballena, la mitad se utilizó con adiciones de azufre, para fluidos de transmisiones, lubricantes de diferenciales y grasas (Hotten, 1972). El aceite de ballena se utilizaba también en procesos de curtiduría, lubricantes de mecanismos de relojería, en la fabricación de cosméticos, producción de ceras y ácidos grasos (Frankel, 1976). Posteriormente a la prohibición de importaciones de Aceite de Ballena, se abatieron las reservas disponibles y se desarrollaron algunos sustitutos obtenidos de grasas de cerdos, ésteres de metilo y productos sintéticos derivados de ésteres de alto peso molecular actualmente en uso (Thomson, 1972).

La cera de jojoba tiene características similares que el aceite de ballena (Greene y Foster, 1938). Puede ser utilizado como sustituto de éste, siempre y cuando su precio sea competitivo con los sustitutos actualmente utilizados.

Entre algunos de los usos potenciales de la cera de jojoba se mencionan: con adiciones de azufre, como aditivo de lubricantes, como componente en tintas de imprenta (Kester, 1948).

Mediante la hidrogenación de la cera de jojoba, se produce cera de excelente dureza con un punto de fusión de 70°C, por lo que se contempla como sustituto de otras ceras vegetales como la candelilla y carnauba (Knoepfler, 1958). La cera de jojoba tiene uso potencial como cera abrillantadora para muebles, pisos y automoviles. Así como en la producción de desinfectantes, surfastantes, emulsificantes, resinas, plastificantes (Kester, 1948).

No obstante la diversidad de aplicaciones que tiene la cera de jojoba, ésta se ha utilizado exclusivamente en la elaboración de cosméticos, dado su alto precio que sólo la industria de cosméticos puede sufragar. El galón de jojoba llegó a cotizarse en 200 Dólares en 1981 (Katoh y Kuhimoto, 1982); actualmente fluctúa entre $30.00 y $40.00 Dls/Galón.

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[1] Ponencia presentada en la Reunión Sobre Manejo de Plantas en Zonas Aridas. Saltillo, Coahuila, México. Febrero 18-22, 1985.

[2] M.C. Ing. Agr. Invest. Lider del G.I. del Prog. de Invest. en Jojoba. INIA - CIANO- CAECH. Apartado Postal No. 1031, Hermosillo, Sonora, México.

Se considera que la superficie de jojoba actualmente en cultivo de aproximadamente 20,000 ha, es suficiente para abastecer la demanda actual (Thomson, 1982). Por lo tanto, es necesario incrementar la productividad de la jojoba cultivada y reducir costos de producción para que ésta sea competitiva con los actuales sustitutos del Aceite de Ballena o como lubricante de uso común. Dado la constante disminución de las reservas de petróleo y el constante incremento en el precio de éste y sus derivados como los lubricantes, es de esperarse que la jojoba tenga en el futuro una demanda extensiva en este campo.

ANTECEDENTES

En 1972 se inició la investigación sobre jojoba en CIANO, el enfoque fue inicialmente provar su adaptación fuera de su ambiente natural. En estos primeros trabajos se recolectó semilla de diferentes localidades en Sonora y Baja California Sur. De la primer siembra se obtuvieron los primeros datos sobre fenología y primeros frutos en 1976. La investigación subsiguiente en CIANO se encaminó a desarrollar tecnología de producción enfocada en fechas de siembra, densidad de plantación, podas y conducción de plantas, fertilización y evaluación de la dinámica insectil en jojoba cultivada, así como la insidencia de enfermedades. Asímismo, se realizaron trabajos para determinar época y cantidad de riegos.

Paquete Tecnólogico

Establecimiento de Plantación: La jojoba puede establecerse mediante la siembra directa de la semilla en el campo o la siembra inicial en macetas para posterior transplante. El primer método resulta ser el más práctico para las regiones donde hay disponibilidad de agua de riego. El transplante de macetas requiere del desarrollo inicial de vivero y posterior transplante, lo que incrementa los costos de establecimiento considerablemente. Este método es recomendado para establecer plantaciones de temporal o reforestaciones en sitios silvestres.

Fecha de Siembra: La semilla de jojoba germina fácilmente a temperaturas entre 21 a 29°C. En la Costa de Hermosillo se ha logrado emergencia de plantas de semillas sembradas en todos los meses del año. Sin embargo, las plantas obtenidas en el otoño o invierno, corren gran riesgo de ser aniquiladas por heladas. Se recomienda realizar la siembra o transplante inmediatamente después del período de heladas.

Fertilización: Los diferentes tratamientos de fertilización nitrogenada de hasta 240 kg de N/ha, no mostraron efecto positivo en la producción de semilla de jojoba. Se considera que el nivel de nutrientes disponible en los suelos de la Costa de Hermosillo es suficiente para llenar los requerimientos de la jojoba. No obstante, es de esperar que estos nutrientes con el tiempo sean redicidos y se presenten síntomas de deficiencia.

Plagas y Enfermedades: Muestreos sistemáticos efectuados en jojoba silvestre con jojoba cultivada con el objeto de estudiar la dinámica de la fauna insectil, indican la presencia de varias especies. No obstante, la única que se considera hasta la fecha como posible plaga es Homalodisca lacerta de la familia Cicadellidae, que se presenta en mayor abundancia de octubre a abril. Esta especie se congrega en las plantas de jojoba dejando excrementos sobre el follaje, sobre los que posteriormente desarrolla fumagina y provoca defoliaciones (Gonzáles V. 1979). De los microorganismos causantes de enfermedades se han detectado a Fusarium oxysporum causando decoloraciones de tejido vascular y marchitez; Macrophomina phaseoli, causando pudrición radicular; Alternaria sp. provocando defoliación y Phymatotrichum omnivorun, causando pudrición de raíz (Romo et al. 1980). En octurbre de 1984 se presentó una defoliación severa en varios lotes comerciales, presumiéndose que fue causada por Cercospara sp. Esta última, por la severidad del daño, puede convertirse en un problema serio que requiere de investigación para prevenir futuras infecciones.

Riego: Los trabajos encaminados a determinar la epoca y cantidad optima de agua de riego, han indicado que el mejor desarrollo vegetativo se logra con 57 cm anuales repartidos en los meses de diciembre a abril. No se ha determinado aún la cantidad mínima óptima de riego para lograr la máxima produción de semilla, debido a la alta heterogeneidad encontrada en las plantas utilizadas. Actualmente se ha establecido un lote clonal para reducir la variabilidad en producción y determinar la lámina mínima (Ortiz, 1980). Ensayos preliminares indican la factibilidad de obtener altos rendimientos de semilla con 35-40 cm de lámina de riego.

Cosecha: La mayor parte de la cosecha de jojoba se realiza en forma manual. Sólo 100 ha en la Costa de Hermosillo son cosechadas mecánicamente con una cosechadora de uva industrial ajustada y que tiene una eficiencia poco aceptable, además de dañar demasiado a la planta.

La cosecha manual es laboriosa, se cosechan aproximadamente 6 kg de semilla limpia y seca por jornal. En una plantación en producción, la recolección representa la mayor parte del costo de producción.

Durante el ciclo 1984 se evaluó comercialmente a iniciativa del productor un sistema de recolección mediante una malla de plástico extendida en la base y a lo largo de las hileras de plantas. Este sistema, según reporta el propietario de la finca logra una eficiencia de hasta 40 kg de semilla limpia por jornal.

Plantaciones Comerciales

A partir de 1977 se iniciaron las plantaciones comerciales en la Costa de Hermosillo, Sonora. Para éstas se utilizó tanto el sistema de siembra directa como transplante en macetas, utilizándose semilla proveniente de poblaciones silvestres cercanas. Las primeras plantaciones establecidas en terrenos de pequeños propietarios fueron financiadas con recursos propios a excepción de 35 ha financiadas por la Comisión Nacional de Zonas Aridas. En la actualidad existen aproximadamente 800 ha de riego y 2300 de tempóral. Estas últimas fueron establecidas a partir de 1980 en terrenos ejidales financiados por COPLAMAR.

En 1980 se inició la primera cosecha comercial de jojoba en la Costa de Hermosillo, lográndose rendimientos de 30 a 160 kg/ha. En años subsiguientes los rendimientos se incrementaron hasta promediar de 300 a 1800 kg/ha en 1983. En 1984, la producción se redujo considerablemente por daño de heladas, lo mismo ocurrirá este año ya que la floración y botones florales fueron severamente dañados el 31 de enero pasado por temperaturas de -4°C.

De las plantaciones establecidas bajo temporal no se ha reportado producción aún. Por las condiciones de sequía en que generalmente se encuentran estas plantas, se reporta una condición de plantas de mala a regular.

Se considera que las plantaciones de riego han sido económicamente rentables, inclusive en aquellas en que se han tenido bajos rendimientos, dado que la producción alcanzó valores de $500,000.00 M.N/tonelada en 1981 y de $700,000.00 M.N. a 1 Millón en años posteriores, no obstante hubo problemas de comercialización. En términos reales, los productores no venden su semilla, sino que la procesan y transforman en cera, siendo éste el producto final. Esta se cotiza en Dólares/Galón y se exporta principalmente a Estados Unidos, de donde posteriormente se exporta a otros países.

En los últimos años, el interés de agricultores privados por establecer nuevas plantaciones de jojoba, ha decrecido considerablemente. Esto es debido a la inseguridad de la comercilización e inestabilidad de la producción. Por otra parte, el apoyo e interés mostrado por algunas dependencias oficiales en la década pasada, también se ha aminorado.

Enfoque Actual y Ultimos Avances de la Investigación

Se calcula que existe un potencial de cultivo de jojoba de aproximadamente 20,000 en el Noreste de México, para abastecer la demanda nacional y para exportación a otros países. De acuerdo a la información proporcionada por los productores sonorenses, el costo de producción de éstos es aproximadamente 43% del costo en Arizona, dando un buen margen para competir en un futuro mercado internacional. Se considera que al estabilizarse el precio de la cera de jojoba y ésta se utilice como lubricante más extensivamente, habrá demanda por tecnología de producción para jojoba cultivada y aprovechamiento de jojoba silvestre. Nuestro objetivo es tomar la delantera y preveer las futuras necesidades de tecnología.

Jojoba Cultivada

El enfoque actual del programa de investigación de CIANO, es desarrollar cultivares de jojoba mediante la selección de plantas altamente productivas y su propagación vegetativa para formación de clones. Paralelamente se continuan trabajos sobre productividad con los clones ya disponibles con el objeto de desarrollar la tecnología adecuada para la expresión de su potencial genético.

La investigación que se realiza en el Campo Agrícola Experimental de la Costa de Hermosillo, está enfocada a desarrollar tecnología de producción bajo riego, dado que en esta zona la precipitación es insuficiente. En la región serrana de Sonora donde ocurren isoyetas de 300 mm o superiores, se tienen lotes fenológicos para estudiar adaptación para temporal.

Jojoba Silvestre

En la Costa de Ensenada, el Programa de Investigación está enfocado el aprovechamiento de las poblaciones silvestres. Los trabajos sobre manejo realizados en las poblaciones silvestres de la Costa de Ensenada incluyen: Reforestación con clones seleccionados, desmontes selectivos, captación de agua, estudios sobre polinización y fenología. De estos trabajos, únicamente hay resultados con respecto al uso de microcuencas para captación de humedad que indican preliminarmente un incremento al doble de la producción del testigo. Los demás proyectos están por iniciarse o iniciados apenas el ciclo pasado.

Desarrollo de Variedades Clonales en la Costa de Hermosillo

La jojoba es una especie dióica por lo que su reproducción es obligadamente halogámica, lo que genera una amplia gama de genotipos, dando lugar a plantas con características de forma y productividad variada. En el CAECH se ha caracterizado la producción individual por planta durante 8 años de cosecha y de esta forma seleccionando las plantas de mayor productividad y de más consistencia (Cuadro 1). Estas plantas fueron propagadas vegetativamente mediante el enraizamiento de brotes terminales (Hogan et al., 1978) y establecidas en un ensayo de rendimiento de clones en el mes de mayo de 1981. Actualmente estas plantas tienen ya 3 años de crecimiento en el campo y han producido dos cosechas.

CUADRO 1. PRODUCCION DE SEMILLA Y CERA DE 14 PLANTAS DE JOJOBA SELECCIONADAS.

CLAVE DE PLANTA	1977	1978	1979	1980	CONTENIDO DE CERA
LA7A	225	777	1000	2135	39.2
LA12D	116	817	605	2125	47.0
LA13B	499	920	1150	1620	45.7
LA27H	102	424	1325	1530	41.4
LA28C	370	502	660	750	37.7
LA36G	459	932	655	1170	41.8
LA39F	674	755	120	820	37.9
LA49H	33	235	1000	1025	47.6
LA24E	369	680	565	1030	-
LB11E	145	550	240	1255	41.2
LB24B	229	907	515	1310	37.9
LB33E	-	997	980	465	41.2
LB51C	30	296	400	1075	39.7
LB57F	10	302	635	1280	39.3

Rendimiento de Clones

Durante el primer año de crecimiento, la producción de semilla fue escasa, sólo una cuantas semillas por planta. La primera cosecha significativa de estos clones fue en el segundo año de crecimiento, teniéndose un promedio general de 130 g. El promedio de producción del mejor clon en este año fue de 314 g (Cuadro 2). Los clones superaron por un año en precocidad a cosecha a las plantas propagadas por semilla.

Durante el tercer año de crecimiento, los clones de jojoba incrementaron su rendimiento promedio a 578 g, que sobrepasa un 30% el rendimiento de las plantas propagadas por semilla (primer cosecha). El mejor clon en ese año rindió 777 g/plants, superando a las plantas propagadas por semilla en 55% (Cuadro 1).

Variabilidad

Al propagrse vegetativamente las plantas de jojoba muestran poca variabilidad en cuanto a su forma de plants o hábito de crecimiento. Sin embargo, se observó gran variabilidad en el rendimiento de semilla entre plantas de un mismo clon (Cuadro 2). Durante la primera cosecha el C.V. general fue de 75% y 62% en la segunda cosecha. En el Cuadro 2 se indica la variación observada para cada clon.

Selección y Evaluación de Plantas Masculinas para Polinización

Inicialmente la selección de machos para polinización se realizaba básicamente en función del vigor de la planta y de su período de polinización que fuera coincidente con la floración de las plantas femeninas, ya que el período de floración de éstas es variable de 3 a 7 semanas. Ultimamente en CIANO (Morales, 1984), hemos podido caracterizar plantas masculinas en función de su capacidad combinatoria de acuerdo al por ciento de amarre de fruto que se obtiene. Estos trabajos se han realizado mediante cruzamientos controlados de plantas musculinas y femeninas y evaluando la frecuencia de frutos logrados según el origen genético del polen. Estos trabajos han indicado que existe una influencia altamente significativa del macho polinizador para lograr el máximo por ciento de amarre de fruto.

En base a estos resultados creemos que la variabilidad en rendimiento entre plantas de un mismo clon se debe en parte a la variabilidad genética de los machos polinizadores. (Los machos polinizadores de los clones provienen de semilla). El potencial genético de varios clones de plantas femeninas de jojoba puede ser expresado utilizando al polinizador con la mejor capacidad combinatoria general.

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CUADRO 2. RENDIMIENTO DE SEMILLA DE JOJOBA Y SU VARIABILIDAD EN CLONES Y PLANTAS PROPAGADAS POR SEMILLA EN DOS AÑOS DE COSECHA.

IDENT.	1983 PROMEDIO gr/PLANTA	1983 C.V. (%)	1984 PROMEDIO gr/PLANTA	1984 C.V. (%)
LA7A	83	60	663	44
LA12D	153	59	603	38
LA13B	123	40	777	50
LA27H	73	112	703	107
LA28C	230	2	766	22
LA36G	38	25	391	58
LA39F	188	57	736	68
LA49H	122	134	655	70
LA24E	164	44	674	66
LB24B	314	28	560	19
LB33E	268	62	540	53
LB51C	19	13	228	82
LB57F	59	138	471	71
SC3	53	59	409	108
PLANTAS DE SEMILLA	-	-	429	77
PROMEDIO GENERAL	138	75	578	62%

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Abstract.--Past research has indicated that there is a great potential for production and commercialization of jojoba. Ecological studies have placed their emphasis on production technology. Current research programs (CIANO) seek to find clones which possess favorable production and propagation characteristics.

Administration of Jojoba Harvesting on National Forest Lands[1]

Donald A. Van Driel[2]

Abstract. Increased demand for the collection of jojoba bean on National Forest lands resulted in an environmental study to evaluate the effects of large scale harvesting; the effects were minimal. Conclusions after several years of harvesting were that litter was the only administrative problem and there were no adverse environmental effects.

It is an honor and a privilege to speak to this international group on administration of jojoba plants on Federal lands in Arizona.

The Tonto National Forest is located in the semiarid mountainous region of central Arizona. The Tonto is divided into six Ranger Districts, but only four contain commercial stands of jojoba.

Jojoba bean collection has occurred in Arizona since the late 1920's. The majority of the jojoba producing land in central Arizona is located on National Forest lands. Although bean collection on National Forests has occurred for several decades, it was not until the early 1970's that demand resulted in a need to look at the environmental effects of high harvest levels on the jojoba plants and their environment. After the First International Conference on Jojoba, which was held in Tucson, Arizona in 1972, the large scale interest in bean collection and oil production occurred. No significant effort was made to regulate bean collection on National Forest lands until 1978. Records indicated that in that year permits were issued for the sale of 14,000 pounds of beans. Sales increased to a record year in 1982 where 368,925 pounds were sold. Since that time sales have been considerably less due to low prices and poor crops.

In 1978 an environmental analysis study was made which evaluated and predicted impacts resulting from the large scale harvesting of jojoba on National Forest lands. The following is a brief look at how this process evolved.

Evaluation criteria was established, identifying the various points that were critical in the development of a jojoba harvesting operation. These criteria points would be used to weigh the various alternatives against the selection of the best method of harvest. First, the harvest operation must be consistent with existing multiple use guidelines. (These guidelines are found in an approved Multiple Use Plan which has determined what activities and uses are acceptable for a given land area.) Secondly, the operation must meet the needs of each Ranger District and the public. Next, the harvest of jojoba beans must ensure the protection of the plant and its associated environment. Last, the agency must be able to adequately administer the program.

The impact of harvesting jojoba was analyzed relative to key social, economic, and resource concerns. What effect would bean collection have on future reproduction of new plants? Would adequate beans be left to ensure plant propogation and how would the agency monitor this impact? How much soil compaction results during harvest operations? Or will harvesting create soil churning? Will either of these soil conditions create long range adverse environmental impacts or are they short term? What effect will harvesting have on wildlife? The pocket mouse is solely dependent on the jojoba bean as a food source--will this animal possibly be displaced by jojoba harvesting in certain areas? Deer and javalina utilize both the bean and forage. What effect will the additional traffic on dirt roads have on air quality? Will trampling by harvesters increase soil movement and decrease water quality? What effect will this trampling have on range forage production? Are there any threatened and endangered plants or wildlife in the harvest area? Will they be impacted? Will the harvesting operations increase the amount of litter and trash in these dispersed areas? How much will it cost to operate and administer a jojoba harvesting operation? Will the program pay it's way? What are the positive and negative social and economic concerns?

As these questions were addressed in the environmental assessment process, several alternatives developed. The Forest Service could choose to not encourage any harvesting of jojoba on Federal lands. Persons found collecting beans on the forest would be cited. Areas of concentrated jojoba stands could be broken into blocks and contracts awarded for collection of beans by commercial harvesters. Large areas could be open for jojoba bean collection and sales would be made over-the-counter to individuals. A combination of over-the-counter and contract sales by designated areas could be made.

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[1] Paper presented at the Meeting on Management and Utilization of Arid Land Plants, Saltillo, Coahuila, Mexico, February 18-22, 1985.

[2] Donald A. Van Driel is the District Ranger at the Mesa Ranger District, Tonto National Forest, Mesa, Arizona.

The combination of individual and commercial sales best met the objectives established in the evaluation criteria and provided the most opportunities for mitigation of any adverse impacts to the affected resources. This alternative also maximized the social and economic benefits by making permits available to all segments of the population. This alternative thus became the preferred alternative in the environmental assessment document.

Although no significant unacceptable impacts were surfaced during the evaluation assessment process, several problem areas, particularly in the administration of a large scale jojoba harvesting program were identified. Due to the generally moderate to low plant densities on the Cave Creek, Globe, and Mesa Ranger Districts and the anticipated high demand due to the proximity of these districts to population centers, it was determined that only over-the-counter, personal sales would be made on these three districts. The Tonto Basin District would make both over-the-counter personal use sales and commercial contract sales. Higher plant densities exist on this district and the areas are more remote.

Off-road travel was prohibited in all harvest areas to minimize soil disturbance and plant damage. No mechanized harvesting would be permitted to reduce the likelihood of severe damage to the jojoba plant itself.

Wilderness areas were excluded from the permitted harvesting areas.

Permits would be available after July 15 of each year. Permit termination dates would vary with the size of the sale--small sales would have a short permit period approximately two weeks per 100 pounds. Larger sales would be permitted a longer time period. Permit durations would also be adjusted depending on the number of persons picking per permit. For example, if the permittee planned on harvesting with a crew of 10 or 15, a 100-pound permit may expire in one week instead of the normal two weeks.

Most districts did not have the manpower to adequately administer the ground harvesting activities. Field personnel are needed to insure pickers are authorized by permit and to enforce the no off-road travel and no mechanized harvesting requirements of the permit. In some cases, large camps developed and agency personnel were needed to ensure impacted areas were cleaned up and equipment removed from the forest at the termination of the permit.

The picking season was initially established from July 15 to December 31. After a few seasons of picking, this time period was reduced to July 15 to September 15. The two major factors contributing to this shortening of the harvest period were: several years of high demand coupled with high product value resulted in a more complete harvest than desirable and in some areas no beans were left for plant propogation and wildlife forage. Due to the Federal Government's budget process most districts also lost the majority of administrative manpower by October 1, when the seasonal workforce is terminated. Typically this results in a 50% reduction in field-going personnel to administer the permits.

Information signs, describing the permit requirement and where permits may be obtained were posted at all major entrance points in English and Spanish. Even with this signing, districts experienced moderate to heavy picking prior to July 15.

Compliance patrols revealed that most people had obtained the required permit. However an Arizona Jojoba Association comparison of total pounds of beans sold by the Forest Service to estimates of total pounds purchased from people picking on Forest Service lands, indicate that as much as five times the amount sold are actually picked from National Forest lands. The problem again is lack of administrative manpower and large harvest areas.

During years when demand and price are high, harvesting pressures occur as long as the market will last. Jojoba prices were particularly high in 1981 and illegal picking occurred throughout the winter. In most cases this late season activity is conducted by organized pickers working independently or for a contractor and they are aware they are in violation of the regulations. These pickers established camps, hidden from the normal flow of traffic and, when approached would run and hide to avoid contact with a forest officer. Again, it is difficult to control this type of activity due to the remoteness of the harvest sites, large number of acres involved, and the lack of manpower.

Trash has become a large problem on National Forest lands. Although the jojoba pickers do not create all our trash problems, they do compound the problem. Most trash resulting from harvest activities is located in more remote areas than other user trash. Picking camps are by far the largest problem. In many cases cars, couches, chairs, tables, and other miscellaneous trash is left behind. Day picker trash most commonly include paper, cans, and bottles. Regular cleanup crews do not collect trash from these remote areas which are managed as "pack in-pack out". Thus the trash is scattered by wind and animals, creating an even larger impact.

It is not uncommon for a large scale commercial organization to supply the money and have numerous individuals come in to buy a personal use permit. The organization will then bring in many hired pickers to work on each of the personal use permits. The commercial areas were established in blocks of land and sold on a bid basis. The individual sale areas were open for many permittees to utilize the same site. This resulted in areas that had been designated for personal use being harvested more intensely than planned. Generally the commercial operators were more thorough in their collection of beans than the individual pickers. The end result was fewer or, in the most severe cases, no beans were left for individuals as well as an overpick from the standpoint of regeneration or wildlife needs.

Harvest of jojoba beans outside the established season created some rather significant impacts to the jojoba plants. The pickers would wait for the beans to fall off the bushes then prune the bushes back so that the beans could be collected from the ground. In most cases the pruning is severe and impacts the ability of the plant to produce maximum livestock and wildlife forage as well as beans during the next growing season.

During years when the demand and price are high, the impacts and illegal activities are also high. During the last several years, administrative problems have been relatively low as a result of both low prices and poor crops. This can also be a result of commercial jojoba farms that are just beginning production.

In conclusion there will be administrative problems associated with the harvesting of jojoba beans, but with the exception of litter, most are not common problems or considered critical. Therefore it is concluded that jojoba beans can be hand harvested annually from native stands with little or no adverse effects on the environment. This conclusion is based on a limited amount of time and knowledge and should not be considered absolute.

Resumen.--El crecimiento de la demanda para la colección de el frijol de jojoba en tierras de forestales nacionales ha resultado en un estudio ambiental para evaluar los efectos de recolección en escalas grande; los efectos fueron mínimo. Las conclusiónes despues de varios anos de cosecha fueron problemas administrativas sobre basuda dejado al compo y los efectos ambiental no fueron adverso.

El Nopal (*Opuntia* spp) y su Utilizacion en Mexico[1]

Facundo Barrientos Pérez[2]

Resumen.--El nopal (Opuntia spp.) es una planta abundante en México y presenta un gran polimorfismo, existiendo diferentes especies silvestres y cultivadas. Para los habitantes de las zonas desérticas y semidesérticas esta planta es muy importante, ya que se le puede utilizar directamente en la alimentación humana por sus frutos o por brotes tiernos de la planta y en la alimentación de ganado, principalmente cuando escasean otros forrajes, debido a la falta de humedad. Industrialmente también se le utiliza para manufacturar productos alimenticios y otros.

Debido a la variabilidad genética del material, a la presión selectiva natural y artificial, así como a la reproducción sexual y asexual es que existen diferentes tipos, los cuales prosperan en diferentes condiciones ambientales, algunos amplimente distribuídos y abundantes como Opuntia streptacantha y Opuntia leucotricha, conocidos como nopal cardón y duraznillo respectivamente. Dichas especies se localizan principalmente en la zona Central Potosina Zacatecana, mencionada por Velázquez (1962), delimitándose 38,000 km^2 con nopal cardón, de los cuales se explotan alrededor del 50%. De duraznillo 45,000 km^2 con una explotación del 15% (Borja 1963).

Algunas zonas como Teotihuacán y otras del Edo. de Hidalgo son reconocidas por la calidad de los frutos que producen sus nopales, en particular la tuna blanca de Opuntia amyclaea. En Milpa Alta, D.F., se le ha dado impulso a la producción de nopal para verdura y se siembra especialmente con ese fin.

INTRODUCCION

El nopal (Opuntia spp.) es una planta nativa de México muy abundante, presenta diferentes formas en estado silvestre y cultivado que dan idea de su evolución y adaptación a diferentes condiciones de clima y suelo dentro del territorio nacional. Esta adaptación, así como la utilización de sus frutos y brotes en la alimentación humana y del ganado, además la elaboración de colorantes, han sído la razón de su importancia en México. En el pasado junto con el maíz y el maguey, fue la base para los primeros asentamientos humanos; en la actualidad y principalmente para los habitantes de las zonas desérticas y semidesérticas esta planta es importante en la alimentación humana y del ganado, en particular cuando escasean otros forrajes debido a la falta de humedad; en el futuro se considera su importancia para contener la erosión del suelo e inclusive la regeneración del mismo; como alimento, fuente de energía y producción de colorantes naturales.

DISTRIBUCION

En México están representados dos subgéneros de Opuntia que son: Cylindropuntia y Platyopuntia, el primero con forma cilíndrica y el segundo con forma aplanada. Al subgénero Platyopuntia pertenecen los verdaderos nopales cuyos frutos se conocen como "tunas" cuando tienen sabor dulce y "xoconoxtles" cuando tienen sabor ácido (Bravo, 1937).

En el subgénero Platyopuntia la clasificación es bastante difícil, debido al enorme polimorfismo determinado por la hibridación. Según Bravo (1937), las especies de este subgénero pueden ser rastreras si desarrollan al nivel del suelo, frutescentes cuando tienen un tallo del cual parten ramificaciones y por último arborescentes, cuando por lo general tienen un tallo cilíndrico desarrollado formado por cladodios viejos, tomando un aspecto característico.

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[1] Ponencia presentada en la Reunión Sobre Manejo de Plantas en Zonas Aridas. Saltillo, Coahuila, México. Febrero 18-22, 1985.

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La posibilidad de cruzamiento mediante una polinización entomófila es frecuente y con posterioridad a la caída de los frutos la diseminación de semillas por aves es posible, obteniéndose variación, la cual puede mantener se a través de una reproducción vegetativa. Debido a la enorme variabilidad de esta planta hay especies que soportan las sequías más prolongadas, así como grandes precipitaciones (116 mm - 2000 mm), asimismo desarrollan desde el nivel del mar hasta los 2600 m.

La mayor abundancia de nopal se localiza en los estados de Zacatecas, Jalisco y Durango, dominando principalmente la especie Opuntia streptacantha y Opuntia leucotricha, conocidas como nopal cardón lo constituyen sus frutos y partes tiernas, empleados con fines alimenticios ya sea en la elaboración de dulces, bebidas alcohólicas y también como frutos de mesa.

Se han delimitado 38,000 km^2 con Opuntia streptacantha de los cuales se explotan alrededor del 50%. El nopal duraznillo se explota principalmente con fines ganaderos eliminando sus espinas. Se distribuye aproximadamente en una superficie de 45,000 km^2 de los cuales se explotan más o menos el 15% (Borja, 1963).

Los nopales tuneros cultivados tienen una distribución principal en los estados de San Luis Potosí, Zacatecas, Aguascalientes; extendiéndose hacia el Sur especialmente en los estados de Querétaro, Hidalgo, Puebla, Tlaxcala, México y Oaxaca.

ESPECIES Y VARIEDADES

Entre las especies tuneras se considera principalmente Opuntia amyclaea conocida como nopal de tuna blanca o de alfajayucan, esta planta se ha distribuído ampliamente en diferentes estados, siendo en Hidalgo en donde más se cultiva. Generalmente próxima a la distribución de ésta especie se encuentra Opuntia megacantha, conocida como tuna amarilla y de un tamaño bastante grande. Opuntia streptacantha o tuna cardona es de la cual se derivan productos como los llamados queso de tuna, melcocha, colonche, etc., esta especie también se emplea ampliamente como forraje y crece como antes se dijo, en condiciones silvestres. Un número de variedades bastante grandes con pocas espinas o ausencia de ellas, pertenecen a la especie Opuntia ficus indica.

Otras variedades que se utilizan en el Valle de México son: (Opuntia spp.) con frutos de un sabor agrio y que tienen un alto contenido de vitamina C y pectinas; con ellos se elaboran dulces, jaleas y condimentan comidas típicas. Otra especie bastante empleada es Opuntia robusta y se utiliza especialmente para complementar algunas bebidas, siendo su fruto bastante grande.

En general, todas estas especies y variedades presentan gran diversidad tanto en el tamaño y forma de sus tallos, como en el tamaño, forma y coloración de frutos.

PRACTICAS CULTURALES

La abundancia y las diferentes formas en que se encuentra el nopal al estado silvestre y cultivado, dan una idea de su evolución y adaptación a diferentes condiciones de clima y suelo, llegándose a la domesticación de algunos grupos que interesan al hombre por las características de sus frutos, brotes o por la potencialidad para derivar productos industriales.

Las prácticas de manejo de la producción y el cultivo también evolucionan desde ecosistemas dominados por especies silvestres, que bajo condiciones naturales el hombre obtiene los productos del nopal, pasando al huerto familiar y finalmente al estado de transición actual, en donde se puede comprobar que a través de la investigación BASICA ORIENTADA será posible experimentar y diseñar esquemas apropiados a las condiciones y necesidades de México.

López y colaboradores (1977), obtuvieron datos representativos de ecosistemas naturales de Opuntia streptacantha, reportan una densidad de 550 individuos de tamaño mayor que 1.50 m, con una producción de 2,557 kg de tuna descortezada por ha; 225 kg por ha de semilla, con 27.8 kg por ha de aceite; el número de frutos producido es de 85,250 con un equivalente de 232.5 kg de queso de tuna por ha. Se considera que por jornal se cosechan y descortezan 4,120 tunas, y se requieren 20.6 jornales por ha para la cosecha. La producción media estimada es de 155 frutos por planta, de 70 gramos por fruto, estimándose una producción de 5,967.5 kg de fruto sin descortezar por ha.

Según estimaciones de Cruz (1981), la superficie cultivada con nopal se aproxima a 6,000 hectáreas, con un rendimiento medio de 6.3 ton/ha, y una producción global de 37,800 toneladas. La superficie cultivada está cubierta con huertos familiares y a nivel comercial en superficies pequeñas con algunas mayores de 100 hectáreas, se obtiene la planta de huertos destinados a producción de fruta y generalmente de las podas anuales. Plantas con dos cladodios son depositados en cepas que varían en tamaño, es común la de 60 cm de largo, 60 cm de ancho y 50 cm de profundidad; se ha observado la ventaja de mezclar estiércol en una proporción de dos terceras partes del volumen de la tierra para llenar la cepa. Las distancias de plantación varían de 6 x 5 m, 6 x 4 m, 5 x 5, 5 x 4 y 4 x 4 las más comunes. Se practica poda principalmente para eliminar pencas mal dispuestas o dañadas. Uno de los principales problemas de estas plantaciones son las plagas que se combaten parcialmente.

La prospectiva de la producción futura indudablemente se apoyaró on los conocimientos basicos de genética, anatomía, morfología, fisiología y bioquímica de los órganos vegetativos y reproductivos de la planta.

Raiz

En general, el sistema radical es superficial y particularmente denso, las raíces muertas proporcionan grandes cantidades de materia orgánica al grado de cambiar el color de los horizontes superficiales de las plantaciones viejas. El parénquima cortical de las raíces gruesas permanece turgente y funciona como un almacén de agua. Las raíces secundarias mueren durante períodos largos de sequía y vuelven a crecer durante el período de lluvias.

Hernández y Barrientos (1978), estudiaron la distribución vertical y horizontal de raíces de Opuntia amyclaea Ten., en plantaciones con suelos de texturas diferentes: Migajón arenoso, migajón arcilloso y migajón arcillolimoso. Se encontró una alta correlación entre el peso fresco y seco de raíces menores y mayores de 2 mm de diámetro; por tanto es posible que los estudios de raíces en esta especie se realicen con el peso fresco. También hay correlación entre el número de raíces de los perfiles y el peso fresco de las mismas; en consecuencia para el estudio de raíces se considera conveniente emplear el método de "perfir o trinchera", ya que a igualdad de eficiencia es más sencillo. La distribución de raíces menores de 2 mm está influenciada por la extensión horizontal del sistema radical, la mayor cantidad de ellas se encontró entre 165 a 215 cm del tranco, y cuando había menor extensión entre 15 a 115 cm; a mayor extensión tales raíces son superficiales (0 a 20 cm). La mayor cantidad de las mayores de 2 mm se localizan entre 15 y 115 cm horizontalmente y entre 0 y 40 cm profundidad.

La información anterior permite el planteamiento de los siguientes temas: no hay necesidad de profundizar en la preparación del terreno para la plantación, más de 40 cm, no es necesario siquiera hacer cepas y menos aún deben ser profundas, ya que como se ha comprebado las paredes de las mismas pueden limitar el desarrollo lateral del sistema radical, bastará entonces con aflojar el terreno y darle pendiente para la captación de agua. Se ha encontrado que a medida que aumenta la densidad de plantación en nopal aumenta la producción de brotes y materia seca total, hasta la fecha se han probado densidades de 10,000 a 500,000 pl/ha sin observar decremento, bajo estas condiciones se observa que a medida que aumenta la densidad, las raíces profundizan más (Barrientos, 1972; Grajeda, 1978).

Tallo y Hojas

En el nopal es común observar hojas pequeñas durante el crecimiento activo del tallo, sin embargo en corto tiempo caen, por lo que en su ausencia el proceso fotosintético se realiza en las partes verdes de los tallos conocidos como "cladodios". La forma aplanada de los cladodios, fue base para considerar el efecto de su orientación en la eficiencia fotosintética, su influencia en la producción de materia seca y en la producción y calidad de frutos. La mayor o menor captación de luz podría manifestarse por una elevación de la temperatura interna y aceleración de los procesos metabólicos. Los resultados confirmaron la hipótesis planteada y en los estudios de Becerra, Barrientos y Díaz (1976) se encontró que los cladodios orientados N-S (caras al E y O), elevan su temperatura con rapidez durante la mañana, la disminuyen al medio día y se vuelve a elevar hasta las 15 ó 16 horas para después bajar continuamente. Por otra parte, los cladodios con posición E-O elevan constantemente su temperatura hasta las 15 ó 16 horas. La temperatura de los cladodios es superior a la del aire durante el día, e inferior durante la noche. Durante la noche sin la presencia de luz se igualan las temperaturas de los cladodios con orientación N-S y E-O, lo que comprueba el efecto de la orientación en la captación de luz y elevación de la temperatura.

Materia Seca

El incremento de materia seca fue mayor en cladodios orientados N-S, con un promedio de 0.270 mg/cm^2/hora; en tanto que los de E-O de 0.124 mg/cm^2/hora. Al aumentar la radiación solar también aumentó la producción de materia seca. Los trabajos de Grajeda, Barrientos y Muñoz (1978), indican que los cladodios más eficientes por su producción de materia seca, son los que producen más brotes y son los que tienen 6 meses de edad en comparación con los de 3 y 12 meses (cuadro 1).

Frutos

Un mayor número de cladodios produjeron fruto cuando estuvieron orientados N-S, hubo mayor número de frutos por planta y por cladodio y un mayor contenido de sólidos solubles, en comparación con la orientación E-O (cuadro 2).

Desarrollo del Fruto

En los trabajos de Alvarado, Barrientos y Laksminarayana (1978), se encontró que las flores son protandrías y abren únicamente durante 24 horas. A las 17 semanas el fruto alcanzó 7.2 cm de longitud y 4.8 cm de diámetro, al momento del amarre ya se tanía el 65.3% de la longitud total del fruto y el 56.5% de su diámetro. Al momento del amarre la cáscara representó más del 95% del fruto y en las últimas 6 semanas el porcentaje de cáscara disminuyó hasta el 36%. Por otra parte, el corazón aumentó a partir de la décima semana en que se pudo separar.

Se encontró una curva climatérica de respiración, durante el desarrollo en la 13a. semana después del amarre y no después de la cosecha, por lo tanto el fruto de nopal se considera como un climatérico.

Cuadro 1. Valores promedio del incremento de materia seca en cladodios con diferente orientación (Becerra, Barrientos y Díaz, 1975)

Experimento No.	Fecha de Realización	Orientación de Cladodios	Incremento de materia seca mg/cm^2/hora		Radiación total Cal/cm^2
		Norte - Sur	0.332		
1	14-X-74			0.211	553
		Este-Oeste	0.089		
		Norte - Sur	0.260		
2	22-X-74			0.210	516
		Este-Oeste	0.159		
		Norte - Sur	0.218		
3	7-XII-74			0.171	382
		Este-Oeste	0.123		

Cuadro 2. Valores promedio de los frutos producidos en cladodios con diferente orientación, en ambos lados de la planta. (Becerra, Barrientos y Díaz, 1975).

Orientación de cladodios	Lado de la planta	Cladodios con Frutos/Planta	Frutos/Planta	Frutos/Cladodios
Norte-Sur	Este	8.4	31.5	2.9
Norte-Sur	Oeste	7.6	28.5	3.1
		N.S.	N.S.	N.S.
Este-Oeste	Este	5.4	16.1	2.7
Este-Oeste	Oeste	5.5	19.2	3.1
	Este	6.9	23.8	2.8
		N.S.	N.S.	*
	Oeste	6.5	23.7	3.1
Norte-Sur		8.0	29.9	3.1
		* *	* *	* *
Este-Oeste		5.4	17.6	2.9

N.S. No significativa estadísticamente.
* Significancia al 0.05 de probabilidad.
* * Significancia al 0.01 de probabilidad.

Cuadro 3. Composición química (inicial) del jugo de tunas cosechadas a diferentes grados de madurez. (Alvarado, Barrientos y Lakshminarayana, 1978).

Composición química del jugo	Días transcurridos después del amarre del fruto					
	91	98	105	110	115	120
Sólidos solubles totales (°Brix)	9,70	13.40	14,55	14.80	15.80	15.50
Acidez Titulable (% Ac. cítrico anhidro)	0,15	0.11	0,12	0,08	0,05	0.03
Acido Ascórbico Verdadero (mg/100 ml)	16,34	13.90	21.40	14,10	11,60	22.05
pH	5,70	6.00	6,20	6,25	6.10	6.60
Glucosa (%)	4.36	7.80	4,67	8.40	11.98	8.19
Fructosa (%)	5.74	6.92	10.06	8.05	5.84	6.71
Sacarosa (%)	1.50	1.03	0,80	0.00	0.00	1.10
Azúcares totales (%)	10,85	15.01	15,22	15.85	17.54	16.04

La gravedad específica del fruto aumentó rápidamente desde la 14a, semana en que fue mayor que 1.0.

Como índices de cosecha se recomienda utilizar la gravedad específica y el contenido de sólidos solubles y físicamente la profundidad del receptáculo (cuadro 3).

En general, podemos decir que los conocimientos anteriores en las especies del género Opuntia han servido de base a los trabajos de mejoramiento genético, prácticas culturales, producción y manejo de la producción de ese frutal.

Variedades Productoras de Fruto

En el programa de mejoramiento de nopal en el Colegio de Postgraduados se ha trabajado principalmente con variedades seleccionadas de la especie Opuntia amyclaea (Tuna blanca o de Alfajayucan). Las F_1 resultantes de la cruza de la colección Mex 23 de San Martín de las Pirámides con la Hgo. 64 de Ajacuba, Hgo., fueron establecidas en lotes de selección en diferentes estados: en semillero por vigor; en vivero, mediante una competencia completa, por vigor, resistencia a frío y a enfermedades y plagas; en planta adulta por adaptación, producción, calidad de fruta y tolerancia a plagas y enfermedades.

Se establecieron lotes en diferentes partes de la República para la estimación de adaptación. En particular en Zacatecas, Aguascalientes, Puebla, Hidalgo, Oaxaca, Yucatán, Guanajuato, Nuevo León, Veracruz, Guerrero, Michoacán, Baja California, Morelos, Durango y en el Edo. de México. Se han obtenido clones de grandes posibilidades tanto por su producción como en la calidad de sus frutos y su producción escalonada.

Los niveles de producción en los lotes experimentales avanzados hasta 1976 produjeron alrededor de 22 toneladas por hectárea para las variedades COPENA T-1 y T-2, en Tecamachalco, Pue. (García Santibáñez, 1976). En la misma localidad, Cruz Hernandez (1981) reportó rendimientos hasta de 30 toneladas por hectárea de fruto, con la variedad COPENA T-3, y rendimientos totales de cuatro años de 85.4 toneladas por hectárea, para la variedad COPENA T-5 (cuadro 4).

El fruto presenta características según las variedades, por ejemplo: el peso promedio de frutos para 1976 fue de 101 gramos para la v ariedad 17 y de 221 para la 19; para las mismas variedades el peso de la cáscara fue de 30 y 99 gramos respectivamente; el peso del lóculo de 80 y 122 gramos; el número de semillas abortivas 59 y 172; y en sólidos solubles 15 y 14% respectivamente. La madurez promedio en la primera variedad es el 10 de septiembre, mientras que en la COPENA 19 es el 10 de agosto (cuadro 5).

Cuadro 4. Producción de variedades de nopal "Copena" bajo condiciones de temporal del Valle de Valsequillo, Pue. (Cruz, H, P. 1981).

Selección	1974	1975	1976	1977	1978	Total	$\bar{X}$
	Producción en ton/ha/año						
Copena T no. 2	3.5	19.8	12.2	21.5	15.3	72.3	14.4
Copena T no. 3	1.4	20.2	12.3	30.0	17.5	81.4	16.2
Copena T no. 5	1.9	13.8	20.5	25.7	23.5	85.4	17.8

Variedades Mejoradas Forrajeras

La variedad mejorada recomendada para forraje se ha designado COPENA F-1*. En las observaciones preliminares, esta planta llamó la atención en los lotes de selección, debido a su rápido crecimiento y ramificación, posteriormente, dentro de otras selecciones se observó que la preferían los roedores y hormigas, lo cual era un indicio de su palatabilidad. Las variedades potenciales se incrementaron rápidamente por el método de fracciones mínimas, desarrollado por Barrientos y Brauer (1964), utilizando partes de la penca con una sola areola para obtener plantas rápidamente.

Las variedades potenciales pertenecían a las especies *Opuntia ficus indica* y *Opuntia robusta*. Valdés G. y Flores V. (1967b) probaron la aceptación del ganado ovino a las variedades mencionadas, encontrando una mayor aceptación para COPENA F-1 cuando tenían libre acceso a todas. También se estudiaron niveles de consumo de las mismas especies, obteniéndose mayores consumos (11.0 kg diarios por animal) de *O. ficus indica* que de *O. robusta* (6.5 kg). Los borregos alimentados con las variedades de *O. robusta* sufrieron diarrea.

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* Colegio de Postgraduados, forrajera 1.

Cuadro 5. Características de variedades de nopal productoras de fruto en Chapingo, México.

No. de Selección	Fecha de maduración	Peso promedio fruto gr.	Peso de cáscara gr.	Peso de lóculo gr.	Semillas normales	Semillas abortivas	Grados Brix
Copena 1	30/8/76	138.3	47.9	90.7	201.9	59.2	16.0
Copena 12	2/9/76	182.8	42.1	90.0	202.9	68.6	15.8
Copena 13	20/8/76	123.0	42.0	79.9	187.3	49.7	16.4
Copena 14	20/8/76	127.2	46.8	76.7	204.7	59.4	16.2
Copena 15	16/8/76	186.6	52.6	83.8	220.9	66.4	15.4
Copena 16	8/9/76	112.0	38.8	72.5	166.8	54.0	15.6
Copena 17	10/9/76	101.0	29.5	79.9	198.9	58.8	15.5
Copena 19	14/8/76	221.3	98.7	122.3	249.9	172.5	14.7

Barrientos (1965) encontró que: (a) los rendimientos de forraje verde son similares cuando se depositan las pencas sobre la superficie del suelo, que cuando se entierran parcialmente, para establecer las plantaciones. Puesto que el primer método es más económico se considera ventajoso su empleo, (b) el nopal responde notablemente al estercolado, (c) con densidades de 40,000 plantas por hectárea, en hileras separadas un metro, con una mínima separación entre plantas (0.25 m) y dos cortes por año, pueden obtenerse alrededor de 400 toneladas por hectárea por año, a partir del tercer semestre de establecida la plantación.

Las dificultades en la estimación de los rendimientos son grandes, en particular, debido a que el mayor contenido del nopal es agua, por lo tanto el tonelaje por hectárea es una medida muy burda de estimación; sin embargo, es un índice del potencial de la planta, inclusive precisamente por su capacidad de almacenamiento de agua.

García (1973), inició un experimento en 1970, para estudiar la producción de forraje verde de nopal, obtenida con diferentes niveles de fertilización y riego. Los niveles de 200 kg de N por hectárea y 100 toneladas de estiércol por hectárea dan el rendimiento máximo por hectárea (186 ton), sin riego; a los mismos niveles y con riego se obtuvieron sólo (175 ton), el testigo produjo en promedio (82 ton). En general se concluye que hay respuesta a la aplicación de estiércol y al nitrógeno y fósforo combinados. En apariencia no existe ventaja en la aplicación del riego bajo las condiciones del experimento. Se nota en este caso, lo mencionado acerca de la variación en las estimaciones de rendimiento, sin embargo es importante observar las tendencias. Se podría comentar que en el caso de García se hicieron cortes periódicos y se estimó el rendimiento mientras que Barrientos (1969), efectuó los cortes considerando la edad fisiológica de la planta y no fechas predeterminadas. Flores (1977) considera que comparando el nopal (COPENA F-1) con otros forrajes que se utilizan actualmente en la alimentación invernal de bovinos de leche en el área de Chapingo tiene buenas posibilidades.

Barrientos (1972), estudió diferentes densidades de nopal en terrenos tepetatosos de temporal en el área de Chapingo, con el objetivo principal de estudiar las tendencias en producción. La plantación se estableció con pencas de un semestre de edad en 1967 y se cosechó en 1969. Las densidades variaron de 5,000 a 80,000 plantas por hectárea, y los resultados obtenidos son los siguientes: para la densidad mínima se produjeron 43,500 pencas y con la máxima 245,250 pencas, equivalentes a (27 ton) y (65 ton) por hectárea, respectivamente. Las observaciones derivadas se podrían resumir como sigue: (a) hay un aumento en el número de pencas cosechadas a medida que aumenta la densidad, (b) el peso promedio de las pencas disminuye a medida que aumenta la densidad, (c) exista un aumento en producción en toneladas por hectárea a medida que aumenta la densidad.

Los resultados obtenidos en los experimentos anteriores nos dan indicaciones muy claras en cuanto al manejo de las plantaciones de nopal para forraje, es decir, es conveniente establecer plantaciones con alta densidad (80,000 ha), lo cual se consigue con surcos de 0.5 m, con plantas a 0.25 m; esto puede realizarse en forma de setos dejando únicamente espacio para el tránsito de vehículos durante el corte; por otra parte, el esquema propuesto da indicaciones para su empleo como seto vivo para detener la erosión, en los terrenos erosionados, pudiendo intercalar otros cultivos en forma de terrazas. La aplicación de estiércol se considera conveniente máxime que se piensa utilizar al nopal para elimentar ganado que a su vez producirá estiércol. El corte deberá efectuarse en forma semestral de acuerdo a las condiciones de crecimiento regionales.

Valdés (1977), determinó la composición química y la digestibilidad aparente de la variedad COPENA F-1 utilizando la recolección de haces en estado de mantenimiento. Considera el autor que es un forraje pobre en nutrien tos, son una digestibilidad regular. De la revisión bibliográfica realizada se concluye: (a) que el nopal es un forraje con un gran contenido de agua y pobre en materia seca, (b) es un forraje tosco en base al nivel de energía que se metaboliza por kg de materia seca, (c) por su energía digestible, se debe considerar al nivel de los forrajes toscos de la época de escasez, como las pajas, rastrojos y silos.

En fecha muy reciente, en la Sociedad Americana de Ciencia Animal, Lastra et al. (1977) presentaron un trabajo que causó gran interés: "Evaluation of thornless prickly pear silages as a feesttuf for ruminants". En dicho trabajo realizado con la variedad COPENA F-1, se hicieron silos con aditivos de gallinaza, urea y urea con melaza. Al comparar con respecto al testigo sin aditivos encuentran que en todos los casos ocurrió una buena fermentación, dando un silo de buen color y olor excepto con la gallinaza. En cuanto a la aceptación fue buena, correspondiendo la mayor con grano de sorgo, urea y melaza y por último can la gallinaza. Todos los aditivos aumentaron en forma significativa la materia seca y proteína de los ensilajes. La digestibilidad (In vitro) de la materia seca y orgánica aumentó con sorgo y urea con melaza. La digestibilidad (in vivo) muestra la misma tendencia excepto, que la urea con melaza fue la más alta. El mayor consumo del ensilaje fue el de nopal y harina de girasol.

Variedades Productoras de Verdura

Se ha seleccionado la variedad COPENA V-1 para verdura, principalmente por su buena capacidad para la producción de brotes suculentos y sin problemas de acidez.

Grajeda (1977) ha logrado con esta variedad producciones elevadas de verdura durante las épocas de más demanda en el mercado como lo es en el invierno, mediante frozamiento en túneles de plástico. La producción promedio en estos túneles ha sido hasta de 40 kg por m^2, en cortes cada 15 días al tamaño comercial requerido. La plantación más eficiente es en forma superintensiva con pencas de un comestre de edad a distancias de 10 cm por 25 cm.

En esta variedad se presentó un ataque severo de la enfermedad conocida por "Engrosamiento de Cladodios" (Pimienta, 1974). Por este motivo fue la primera variedad en donde se ha producido material fundador por medio del cultivo de tejidos (Barrientos, 1976).

PLAGAS Y ENFERMEDADES

El nopal empleado para verdura presenta pocos daños de plagas; sin embargo, recientemente se ha incrementado una enfermedad, posiblemente virosa, caracterizada por el engrosamiento de cladodios y suspensión del crecimiento. Mediante tratamientos de calor y cultivo de meristemos *in vitro* fue posible obtener plantas sanas, lo cual ha permitido obtener material 'fundación' y las metodologías de propagación que serán la base de programas de certificación (Barrientos, 1964, 1978).

En los últimos años ha proliferado una enfermedad bacteriana que causa pudriciones, que destruyen a las plantas con suma rapidez, sobre todo en ambientes fríos y con alta humedad relativa, se ha caracterizado el género Erwinia como el organismo causal, pero la especie no esta determinada.

Otra enfermedad conocida comúnmente como el 'Oro', está relacionada con cambios bruscos de temperatura, que producen daños que facilitan la entrada de microorganismos.

Los nopales productores de fruto presentan daños considerables por las plagas siguientes: *Cactophagus spinolae* Gyll., *Cylindrocopturus biradiatus* Champ., *Hesperolabops gelastops* Kirk., *Sericothrips opuntiae* Hood., *Laniifera cyclades* Druce., *Olycella nephelepasa* Dyar., *Dactylopius indicus* Green., *Chelinidea tabulata* Burm.

García Mayoral (1965) considera que el combate de las plagas del nopal puede hacerse mediante las medidas generales siguientes:

(1) Destrucción de toda clase de malezas que crezcan en el terreno cultivado con nopal a fin de mantenerlo limpio.

(2) Revisión constante de las nopaleras nuevas libres de plagas y destrucción inmediata por medios mecánicos de cualquier brote de aquellas especies de mayor tamaño (grandes), como *Cactophagus*, *Laniifera* y *Olycella*, mediante la captura y extirpación y extirpación de larvas y adultos.

(3) Si el cultivo ya está infestado, los procedimientos generales de combate son los siguientes: captura y extirpación de las especies grandes en la época de mayor incidencia. Las otras especies pueden ser atacadas eficazmente con insecticidas en polvo.

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Summary.--The brick pear (Opuntia spp.) is an abundant plant in Mexico and presents a great polymorphism, many different wild and cultivated species exist. For the inhabitants of the desert and semidesert areas, this plant is very important, as its fruits or tender buds can be used directly for human food and for cattle food as well, mainly when other forages are scarce due to the lack of moisture in the soil. It is also used in industry for the manufacture of food, and in other products, too.

Because of the genetic variability of the material, the natural and artificial selective pressure, as well as of the sexual and asexual reproduction, there are different types, which grow in different environmental conditions. Some of them are highly distributed and are very abundant, such as Opuntia streptacantha and Opuntia leucotricha, known as "nopal cardón" and "Duraznillo", respectively. Such species are mainly found in the Potosina-Zacatecana Central Area, mentioned by Valazquez (1962), delimiting 38,000 km^2 for "nopal cardón" of which approximately 50% is exploited; and, 45,000 km^2 for the "duraznillo" of which 15% is exploited (Borja, 1963).

Some areas as the one in Teotihuacan and others in the state of Hidalgo are known by the quality of the fruits of their brick-pears, particularly the white fruit of the Opuntia Amyclaea. In Milpa Alta, D. F., the brick-pear is raised as a vegetable, and it is mainly sowed for this purpose.

The Prickly Pears (*Opuntia* spp.): Plants with Economic Potential[1]

Charles E. Russell and Peter Felker[2]

Abstract.--The cactus family contains many economically promising species primarily in the genus Opuntia. This genus appears to have its center of genetic diversity in Mexico where it is widely used for fodder, forage, fruit and green vegetables. Since the Crassulacean Acid Metabolism of the Cactaceae can result in a four- to five-fold greater efficiency over most grasses in converting water to dry matter, cacti are ideally suited for water-short areas. In the southwestern United States, prickly pears (e.g. Opuntia lindheimeri) have been considered both weeds and valuable forage plants. This presentation discusses Opuntia spp. as crops such as fodder, forage, fruit and green vegetables. We specifically discuss their potential as a range forage to ensure an inexpensive stock feed during the frequent, unpredictable droughts in South Texas and northeastern Mexico. During these droughts, propane torches, known as "pear burners", are used to singe the spines off cactus pads so that they can be eaten by livestock. Although thornless varieties of Opuntia can be consumed directly by domestic livestock, they are subject to herbivory by wildlife as well. As an emergency stock feed, cacti are more dependable than grass and may offer a means of extending greater sustained carrying capacity to certain drought-prone rangelands.

INTRODUCTION

In North America prickly pear is the common name for any flat-stemmed cactus of the genus Opuntia. Historically and prehistorically, these cacti have played an important role in the life of the inhabitants of present-day Mexico. The founding of Mexico City in 1325 on an island in Lake Texcoco was based on an omen containing reference to "nopal" or cactus. In his book on the discovery and conquest of Mexico, Bernal Diaz describes the fruits and pads of cacti as common food when he and Hernando Cortes entered Tlascala in September, 1519. References to cacti abound in the mythology and art work of ancient and present-day Mexico where a cactus is part of the emblem of that nation.

Most of northern Mexico is considered arid or semiarid. In this area cacti make up a large part of the vegetation and are used extensively for human food, as well as animal fodder and forage. (The word fodder is used in this paper for plant material grown and harvested for livestock, whereas, forage is material range animals seek and consume in the field.) Thus, it is appropriate that this work on cacti began in Mexico where scientists such as Roberto Nava C. at the Universidad Autonoma Agraria Antonio Narro, Efraim Hernandez X. and Ernesto Riquelme V. at the Colegio Post-graduados, Chapingo, were able to suggest sites to visit as well as provide information and data on the ecology and use of cacti.

Despite the widespread use of cacti in Mexico and other parts of the world, there has been little applied research on their use in the United States since the pioneering work of Griffith from 1905 to 1915. Unfortunately, while there is little doubt cacti are important food, fodder and forage crops worldwide, the scientific literature on their economic potential is too old and fragmentary to begin research without field-trial validation and a thorough review of the Mexican, North African, South African and South American literature which is not easily obtained in the United States. Consequently, we have begun a two-year project to collect literature and germplasm for the field evaluation of selected cactus varieties.

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[1] Presented at the Reunion Sobre Manejo Y Utilizacion De Los Plantas De Zonas Aridas as part of the cultural, scientific and technical program previous to the IX World Forestry Congress, sponsored by the Secretaria De Agricultura Y Recursos Hidraulicos of Mexico and the USDA, February 18-22, 1985, Saltillo, Coahuila, Mexico.

[2] Senior Post-doctoral Fellow and Associate Research Scientist.

GENETIC RESOURCES AND NATURAL DISTRIBUTION

The Cactaceae family contains approximately 130 genera with about 1,500 species which are originally native only to the New World (Monjauze and Le Houerou 1965). Although cacti are primarily associated with dry subtropical areas, Opuntia polycantha Haworth occurs at 53°N latitude in Alberta, Canada, and O. australis Weber occurs at 50°S latitude in southern Argentina. O. rafinesquei Engelm. has become naturalized in the mountains of Valais, Switzerland, and undoubtedly possesses the greatest cold tolerance (Monjauze and Le Houerou 1965).

Feldger (1979) described three major growth forms of economically important cactus: the large columnar cacti, the shrub-sized prickly pear and chollas, and the small pin-cushion cacti. He also cites work indicating a high degree of hybridization within the family. The Opuntia species studied to date appear to be a polyploid series containing diploid (2n = 22), tetraploid and octaploid forms which are propagated vegetatively (Hernandez X. 1970).

Opuntia ficus-indica L. was introduced to Spain from the New World by Christopher Columbus. Within a short time, it had become naturalized throughout Spain and in 1610 was carried to North Africa with the last departing Moors. Due to Spain's influence, Opuntia ficus-indica had spread throughout Italy, Greece and the Mediterranean by the end of the 18th century. In 1965, it occupied 100,000 ha in Sicily, 6,000 ha on Sardinia and 60,000 to 80,000 ha in Tunisia (Monjauze and Le Houerou 1965).

All cactus plants have Crassulacean Acid Metabolism (CAM) and can thus have a four- to five-fold greater efficiency than most grasses in converting water to dry matter (Kluge and Ting 1978). Because they are so water use efficient, cacti are ideally suited for many arid and semiarid ecosystems.

CACTUS AS A FRUIT CROP

Griffith and Hare (1907) reported that in 1905 Italian varieties of cactus fruit or prickly pear (known as "tunas" in Spanish) were available in Washington, D.C. markets for several months. At that time, cactus fruits in commercial use typically were pear- or fig-shaped and 2-7 cm in diameter. The amount of pulp in the various varieties they studied was from 30-60 percent with the best-tasting varieties containing the largest percentage of pulp. Griffiths and Hare (1907) also described various cottage industries and products prepared from the cactus fruit and fruit juice. Among those products were "tunas secas" or dried fruit, "colonche" a fermented drink, a fermented drink, "miel de tuna" (tuna honey), which was a molasses or honey-like product, and "queso de tuna" (tuna cheese), a product similar to pulled taffy.

More recently, we have observed and purchased fruits in California, Chile, Mexico and Texas. Analysis of a commercial Chilean cultivar, grown in our greenhouse, by the USDA Agricultural Products Quality Research Laboratory in Weslaco, Texas, revealed that the fruit had a pH of 5.8 and a fresh-weight sugar content of 0.2% sucrose, 7.0% glucose and 4.8% fructose. In addition, a taste panel of 10 individuals rated the fruit at 7.6 on a scale with a maximum value of 9.

Hernandez X. (1970) reported that in Mexico eight metric tons of top quality fruit can be expected within four years of plantation establishment at a plant density of 2,000 per hectare. Full production is reached in about the twelfth year and continues for at least 20 years thereafter. A two- and one-half-year-old plantation in San Luis Potosi, Mexico was visited in May of 1984 by Russell (unpubl. data) which had a plant density greater than 2,000 per hectare and was bearing its first crop. The selected varieties in this plantation were coming into production a full year sooner than those cited by Hernandez X. (1970).

Since Dr. Barrientos will undoubtedly discuss tuna production in Mexico, we wish to mention a South American country which has an economically important tuna industry. In Chile there are active research programs at both the Pontificia Universidad Catolica, led by Antonio Lizana M., and the Universidad de Chile, under David Contreras T. and Fusa Sudzuki H. on tuna production, marketing, postharvest physiology and utilization. In Chile tunas are grown in well-organized plantations either in monoculture or, at times, intercropped with tree fruit such as almonds, apricots and olives (Russell, unpublished data, 1984).

It is reported that the better plantations produce 9 to 15 tons of fruit per hectare (Toroni C. and Zuniga O. 1983). In the tuna producing areas of Til-Til, Pudahuel and Noviciado where irrigation is available, fertilized plantations produce two crops per year. There is a summer crop from February through April and a smaller, but economically important, winter crop in October. In response to questions about growing tuna where tree fruit or grapes could be grown, the growers indicated that with less infrastructural costs tuna production is as profitable on their marginal lands as tree fruit or grapes. This is particularly true on sloping land or where they do not have irrigation.

It thus appears that there is ample diversity within commercially accepted varieties for adapting prickly pear fruit production to differing climatological, management, and soil conditions. The pulp-to-seed ratio and shelf life compare favorably with traditional fruits and berries on the commercial market in the U.S. Thus, consumer acceptance should not be a problem if the fruit was available in the U.S. Given current agricultural land values in semiarid areas, it is probable that cactus fruit production could substantially increase returns to landowners.

CACTUS AS A VEGETABLE CROP

"Nopalitos" are the tender, young pads of the cactus plants eaten as a vegetable in Mexico and the southwestern United States where there are large populations of people with a Mexican heritage. In the Lenten season, these pads are prepared as a cooked green vegetable or a marinated vegetable particularly during "Holy Week." In Mexico, the production of nopalitos as a vegetable crop is centered in the areas of Milpa Alta, Distrito Federal, the state of Mexico, and the state of Puebla. Milpa Alta was visited at the suggestion of E. Hernandez X. in May 1984 and crop production was discussed with several growers (Russell, unpubl. data). Milpa Alta, which means "high corn field," is a small valley at about 2400 to 2600 m elevation in the shadow of Popocateptl about 25 km south of Mexico City.

At the time of the visit the entire cropping area of the valley was in nopalito production with a cactus known as nopal de Casailla (Opuntia ficus-indica). Plantations for vegetable production have about 40,000 plants per hectare planted about 30 cm apart within rows and 80 cm between rows. The first crop can be harvested in two or three months and well established plantations yield 80-90 metric tons per hectare (Anon. 1981). Material which is not sold on the vegetable market is used for dairy cattle fodder. The local dairy operations supply the fresh manure which is liberally applied to the fields every third year for moisture conservation and the only source of fertilizer.

At the time of the visit, Milpa Alta appeared to be a remarkably prosperous area. The reason given by local growers for changing from corn to cactus was that corn was frequently a marginal crop dependent on the highly variable rainfall, and they could consistently make more money growing cactus. Thus, the steep, semiarid land at Milpa Alta might serve as an example of converting marginal land into productive land by simply growing an ecologically appropriate crop.

CACTUS AS FODDER AND FORAGE

South Texas and northeastern Mexico are semiarid to subhumid climatic environments. The growing season exceeds 300 days, and the average rainfall ranges between 380 mm and 720 mm with a bimodal precipitation regime. Although a median rainfall can be calculated, the area is characterized by pronounced variability with no predictable rainfall (Norwine, 1981). Local ranchers maintain that three or four out of seven years will be drought years from the standpoint of obtaining a grass crop on rangelands. This unpredictability creates problems for range management which frequently result in rangelands being severely degraded by overgrazing. This is further exacerbated by cattlemen generally equating rangeland with grassland regardless of its ecological validity in the local environment.

Frequently large sums of money are spent converting coastal plain and chaparral into grassland which can be maintained for limited periods. Animal unit allotments based on the estimated forage production of the introduced grasses generally use the median rainfall estimate which, as shown in Figure 1, is not predictable for the anticipated growing period.

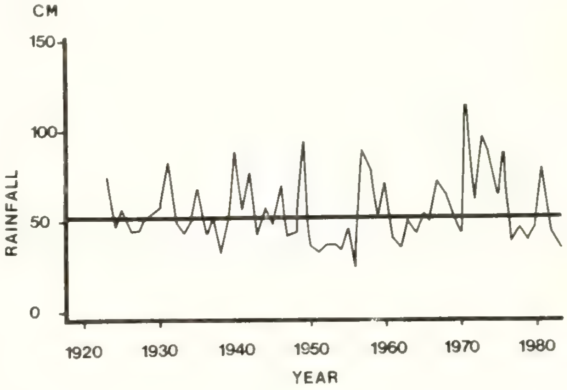

Figure 1. Total annual precipitation, Cotulla, Texas (1923-1983). Data from NOAA, National Climatic Center, Ashville, N.C.

In light of the known variability of the precipitation regime, we believe that prickly pear should be included in any range management scheme in this and similar areas throughout the world. The vegetative part of the cactus can be spiny or spineless and has been widely used for livestock fodder and forage in semiarid regins. While cactus is low in protein, its digestible energy production per unit of water is high. Thus, cactus should provide a good complement to semiarid-adapted nitrogen fixing, high protein plants like Leucaena (Brewbaker and Hutton 1979), Prosopis (Felker and Clark 1982) and the grasses preferred for livestock forage.

Cactus has been described as an unbalanced ration that is low in protein and lipids, but rich in digestible carbohydrates, water and vitamins (Monjauze and Le Houerou 1965). It is perhaps fortunate that cactus is low in protein, otherwise, its leverage of water to dry matter production would be nitrogen limited. The fresh and estimated dry weights of cactus pad production are presented in Table 1. Dry weight yields were generally not reported, but were calculated as 13 percent of wet weight from a review of 13 cactus productivity reports by Monjauze and Le Houerou (1965). The highest yield is from a well-established and tended experimental plot at Chapingo, Mexico (Riquelme V., pers. comm., 1984). The dry weight yields are high for semiarid ecosystems and indicate that with variety selection and some basic research, target values of 30 to 40 mt/ha/yr are reasonable.

In South Texas, prickly pear (e.g. O. lindheimeri Englem.) is widely known as an emergency drought feed for cattle. In drought periods when grasses have been overgrazed or become senescent, cactus remains succulent and green, with a normal complement of vitamins and carotenoids (precursors to vitamin A). Numerous modifications of propane torches known as "pear burners" have been used to singe cactus spines so that cattle can eat the pads. During the drought of the 1950s in Texas, pear was held in high esteem by cattlemen.

We suggest that prickly pear can be grown as a fodder crop on land which is presently deemed marginal for other crops (e.g. corn and sorghum) because of its greater water-use efficiency. This fodder can be of either the spiny or spineless varieties (Griffith 1908). In addition to burning the spines off with pear burners, harvested spiny pads can be tumbled and chopped to remove the spines for confined cattle in a feed lot or dairy operation (Griffith 1905, 1906).

In the northeast of Brazil, Opuntia ficus-indica has been grown as a fodder crop for about 80 years. Presently, there are approximately 300,000 hectares in cactus plantations, about 95 percent of which are located in the states of Paraiba, Pernambuco and Alagoas. At the EMBRAPA/CPATSA experiment station near Petrolina, Pernambuco, Severino Gonzaga de Albuquerque has been conducting field trials for three years on various intercropping regimens of cactus, with mesquite or algaroba (Prosopis spp.), grain sorghum (S. bicolor) and cowpeas (Vigna unguiculata) (Russell, unpublished data, 1984). This area is notoriously dry, has a brackish water table just a few meters below the surface, and receives all of its annual precipitation during one short rainy season. Thus, ranchers are faced with an approximately 40 week drought every year. Local ranchers claim cactus is the only thing they have to carry livestock through the annual dry season. It provides not only the carbohydrates, but also biological water (i.e. the water stored in the cactus pads) in an area where there is no surface water 80 percent of the time in a normal year. These ranchers are in essence farming water!

Finally, prickly pear can be used to provide greater sustained carrying capacity to drought-prone rangelands. By incorporating it into a more diverse range ecosystem, it can assure abundant emergency stock feed during drought seasons. Presently in South Texas, it costs about 35 cents per animal unit per day to maintain cattle on prickly pear, whereas "relief"

Table 1. Summary of cactus dry matter production.

Location	Rainfall (mm/yr)	Cultivation	Freshweight mt/ha/yr	Dryweight[1] mt/ha/yr	Source
Mexico	-	-	400	52	Riquelme V., 1984
Mexico	-	-	200	26	Hernandez X., 1970
Italy	-	-	60	7.8	Monjauze & Le Houerou, 1965
Sicily	-	-	60-65	7.8-8.5	Monjauze & Le Houerou, 1965
Morocco, S. Africa, Algeria	-	-	100-300	13-39	Monjauze & Le Houerou, 1965
Brazil	300	-	140	18	Monjauze & Le Houerou, 1965
Tunisia	150-400	No	25-102	3.2-13	Monjauze & Le Houerou, 1965
Brownsville, TX	-	-	44-123	5.7-16	Griffith, 1915
San Antonio, TX	700	Yes	51	6.6	Griffith, 1908
San Antonio, TX	700	No	6.3	0.81	Griffith, 1908

[1] The 13% dry matter content used here was typical of 13 dry matter values reported in the review of Monjauze and Le Houerou (1965).

corn supplied by the federal government from its reserves costs 78 cents per day, and alfalfa is about 109 cents per animal unit per day (Maltsberger, per. comm.). If cattle must be carried for an extended period on cactus, they need an additional 24 cents-worth of cottonseed meal per day. Since it is not uncommon to carry cattle 100 or more days before unpredictable rains allow other forages to come back, the economics (e.g., 50 cents per animal unit per day) are clearly in favor of prickly pear over alfalfa or infrequently supplied "relief" corn from the government.

As an example, one cattle producer in South Texas has had his cattle on prickly pear and either cottonseed or cottonseed meal for more than a year now. During this period of time, the area has suffered one of its frequent droughts. While his neighbors have had to sell off their cattle or let them die, he has increased his herd eight percent. He also states that the conception rate of his Santa Gertrudis cattle is four to five percent better for a 60-day breeding period than if they were on normal dry grass range. In December, 1984 he sold dry cows at about 42 cents per pound (live weight) weighing an average of 1200 pounds (545 kg) each. In February, 1985 he again sold dry cows, but at 52 cents per pound, weighing an average of 1285 pounds (583 kg) each.

This rancher now believes that cactus should be a permanent part of his cattle operation. He is no longer going to wait for a drought to utilize prickly pear, but will continue to feed his cattle cactus every year whether it rains or not. He is thus planting prickly pear in rows to increase the fuel use efficiency to burn the spines off. He is going to try to use cactus for 30 percent of the total annual diet in normal years (400-500 mm) and 50 to 60 percent in dry years. By using cactus to supplement the diet of his cattle, he will increase both the carrying capacity of his land and the quality of the range for forages other than cactus.

The ability to carry livestock over a drought on prickly pear has tremendous implications for drought-prone areas. If producers can avoid selling when a drought begins and then trying to catch up with their forage by buying back livestock when the drought ends, they can avoid the common "buy high and sell low" cycle so prevalent in semiarid regions. The more stable livestock population numbers remain, regardless of the drought cycle, the more profitable the ranching operation should be.

In addition to feed for livestock, prickly pear provides food and cover for wild animals. In some areas of the western United States and northern Mexico, hunting revenues equal or exceed the income from livestock production, suggesting that ranchers should consider the other benefits of prickly pear on their rangelands (Ramsey 1965; Teer 1975; Arnold & Drawe 1979; Everitt & Gonzalez 1981).

CONCLUSION

We have discussed the potential of cacti, fruit and vegetable crops. Its water-use efficiency and long history of use in Mexico suggest it would be valuable in other semiarid ecosystems, both in the United States and elsewhere. We especially want to draw attention to the possibility of using prickly pear as forage crop in drought-prone areas. The vegetative part of the cactus can be spiny or spineless and has been widely used for livestock fodder and forage in semiarid regions. The spiny varieties should be planted or encouraged, not eradicated. During favorable forage production years, these plants, protected from animal predation by their spines, would sequester water and mineral nutrients while producing carbohydrates and vitamins which could be made available during drought seasons more economically than alternative feeds. Although thornless varieties of Opuntia spp. can be consumed directly by domestic livestock, they are subject to considerable herbivory by wildlife as well.

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Resumen.--La famila de cactus contene muchas especies de importancia económica, particularmente en el género Opuntia. Este género parace que tiene su centro de diversidad genética en México donde se usa como pastura, forraje, fruta y verduras verdes. Porqué el metabolismo acido crassulacean de Cactaceae puede resultar en quatro a cinco veces mas eficiencia sobre más de otro gramineas en convertir agua a materia seca, cacti son idealmente adecuados par areas aridas. En el suroeste Estadio unidos, nopales (e.g., Opuntia lindheimeri) se han considido como malezas y plantas forrajedas de importancia. Agui se discute Opuntia spp. como cosechas de pastura, forraje, frutas y verduras verdes. Discutimos especificamente su potencial como forraje de campo para asegurar un alimento barato de ganaderia durante las frequente y incierta sequías en Texas sur y nordeste México. Durante estas sequías, antorchas de propano, conocidas como "quemadoras de nopal", se usan para chamuscar las púas para se puedan come por ganaderia. Aunque variedades de Opuntia sin púas se consumen directo por la ganaderia, tambien son consumido por la fauna sylvestre. Como alimento de emergencia para ganaderia, cacti son mas confiable que gramineas y pueden ofrecer un modo de extender mas la capacidad de mantener a siertos pastizales que sufren sequías.

Impacto de la Ganaderia en la Utilizacion de Especies Nativas y su Clasificacion en el Estado de Sonora[1]

Ing. Rafael Aguirre Murrieta[2]

Resumen.--El usoy manejo de las plantas forrajeras de las zonas áridas de Sonora es inadecuado y la utilización exceciva y destructiva, además de que algunas plantas aunque forrajeras, quizás tienen para el futuro otros valores y usos, inclusive en la alimentación humana e industrial; falta investigación y experimentación educación y entrenamiento y técnicas expecializados en el manejo, conservación y mejoramiento de éstos recursos bióticos.

Una de las utilizaciones más grandes, en forma masiva, que se hace de las plantas de las zonas áridas, es realizado por el ganado doméstico y fauna silvestre de las llamadas plantas forrajeras y que en el Estado de Sonora son parte medular de la actividad y economía ganadera.

La ganadería es una actividad económica sumamente importante, que representa después de la agricultura, la ocupación más generadora de empleos divisas y alimento básico. Pero en el desarrollo tecnológico aplicado se considera un atrazo entre 50 y 60 años, en relación a la agricultura. Este atrazo ha traido como consecuencia un mal manejo de los recursos del pastizal y es en gran parte culpable actual de la situación del deterioro de estos recursos tales como:

Destrucción acelerada de la vegetación invasión de-plantas no forrajeras y toxicas al ganado

Alza en los costos de producción

Baja producción animal

Erosión acelerada

Asolve en las presas, que acortan su vida útil

-Escurrimientos de alta velocidad que provocan daños, inundaciones y erosión. -Perdida en la capacidad de captación de agua en las cuencas hidrologicas. -Baja en cantidad y calidad de aqua para las Zonas agricolas y Centros urbanos en las Zonas bajas.

Existen evidencias en cambios de vegetación en algunas Zonas en los ultimos 80 años que coinciden con el desarrollo de la ganaderia en el Estado, síendo en éste, donde se encuentra mayor información al respecto, existieron a fines del siglo pasado y principios del presente alrededor de 10 milliones de has. de pastizales abiertos y asociados con arbustos y arboles en la actualidad existen 2.3 millones de has. de los cuales en 1966 al iniciar COTECOCA los estudios de vegetación 250 000 has. eran de pastizal mediano abierto, con dominancia de especies del genero Bouteloua y actualmente este pastizal se encuentra deteriorado con procesos graves de erosión e invasión de gramineas anuales y especies arbustivas no forrajeres, pudiendose decir, que ya es un pastizal con arbustos como el resto del pastizal encontrado y este ultimo ya presente invasiones de especies de matorrales.

Sonora tiene 18.5 millones de ha., de las cuales el 75% se consideran de agostadero; se han identificado y delimitado 25 tipos de vegetación entre bosques, pastizales, matorrales, selva baja, etc. ademas de la vegetación costera de dunas, halófitas y manglar; dominando en superficie los matorrales y pastizales de zonas áridas y que ocupan el 89% de la superficie de agostadero.

Dentro de estos tipos de vegetación se han identificado alrededor de 58 sitios de productividad forrajera, clasificandolos dentro de cada tipo de vegetación del mas al menos productivo segun sus especies forrajeras claves.

Dentro de esta clasificación se han elaborado listas de plantas forrajeras enlistandolas como deseables y menos deseables desde el punto de vista de manejo de pastizales y tipos de menos deseables o invasoras que no por no ser forrajeras dejan de tener importancia ecológica y económica para otros usos, como el caso de la "gobernadora" Larrea tridentata, "calabacilla de coyote" Cucurbita feotidissima, "caña agria" Rumex hymensepalus, por mencionar algunas.

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[1] Ponencia presentada en la Reunión Sobre Manejo de Plantas en Zonas Aridas. Saltillo, Coahuila, México. Febrero 18-22, 1985.

[2] Ing. COTECOCA-SARH.

La utilización más grande y peligrosa desde el punto de vista ecológico es sobre las plantas forrajeras, de las cuales se tiene aproximadamente una lista de 500 especies con mayor o menor grado de potencial alimenticio para el ganado doméstico y fauna silvestre.

Entre las principales especies se cuentan 381 spp. de 93 géneros de gramíneas entre perennes y anuales, de las cuales el 90% son forrajeras; 24 spp. de árboles y 53 spp. de arbustos, principalmente leguminosas y 16 spp. de hierbas perennes y algunas anuales.

Pero la problemática del uso de éstas plantas es la sobreutilización por sobrepastoreo que de ellas se ha hecho por años, a tal grado, que por regiones algunas de ellas ya han desaparecido, además de los daños antes mencionados, afectan la economía del mismo ganadero por baja producción de crías.

Tenemos estudiadas a fondo 7.3 millones de ha. del Estado a nivel predial y municipal y encontramos una erosión leve en el 21% moderada el 59% y grave el 20% de éstas superficies; la tendencia de erosión es de 70% negativa, 21% estabilizada y solamente el 9% positivo o a establizarse.

Este sobreuso por años tiene raíces de caracter agrario-legal y socio-económico y una falta de legislación y reglamentación adecuada, práctica y fácil de aplicar, aunque en 1984 se hizo una nueva ley de ganadería en la entidad con un capítulo sobre la explotación, conservación, manejo y mejoramiento de los recursos forrajeros de los pastizales, ésta ley carece aún de reglamentación y no se ha podido aplicar por ésta carencia y factores socio-políticos.

También se carece de programas de extensión y educativos que penetren en la conciencia de los usuarios sobre el manejo más adecuado de sus recursos, así como de una investigación y experimentación, sistemática, masiva y de largo plazo sobre arbustivas forrajeras.

Si bien algunos centro de investigación de la zona han trabajado con gramíneas y algunas arbustivas, todas o casi todas son de introducción de otras partes del país o del extranjero, pero no se ha hecho nada o casí nada con la especies nativas.

Tenemos muchos trabajos y muy importantes y exitosos con zacate buffel *Cenchrus ciliaris* y podemos considerar que en Sonora ya esta naturalizado; con algunas especies de Atriplex, Kochia y otras se han hecho algunos trabajos de introducción y adaptación en la Península de Baja California, pero no conocemos resultados de producción y comportamiento bajo pastoreo y siempre se está tratando de buscar nuevas plantas forrajeras pero fuera de la entidad o del país.

Abstract.--The management of forage plants of the arid lands of Sonora is inadequate, and the utilization is excessive and destructive. Some forage plants may have other values and uses for the future, inclusive of sources of food for human consumption and industrial. There is a need for additional research and experimentation with native plants for awareness programs, education and training, and new techniques, especially those dealing with management, conservation and development of these biotic resources.

Weeds Common to Mexican and U.S. Rangelands: Proposals for Biological Control and Ecological Studies[1]

C. Jack DeLoach, Paul E. Boldt, Hugo A. Cordo,
Hyrum B. Johnson, and James P. Cuda[2]

Abstract.--Several species of woody and herbaceous plants are serious weeds of rangelands in the southwestern United States and northern Mexico. Biological control by the introduction of organisms (especially insects) from other areas of the world (especially Argentina) is a possible method for controlling native species such as Gutierrezia, Baccharis, Flourensia, Larrea, Prosopis, Hymenoxys, Aloysia, Astragalus, Drymaria, Juniperus, Acacia, and introduced species of Tamarix and Salsola. From these species, targets for control are selected by considering the amount of damage caused, beneficial and ecological values, and potential for success. Weeds that presently seem acceptable both to the USA and to Mexico are Gutierrezia, Baccharis, Flourensia, Hymenoxys, and Drymaria; additional species could be considered if conflicts of interest can be resolved. Studies in the USA are determining the ecology of shrub invasion in grasslands, particularly by Prosopis, Juniperus, and Opuntia. Information is needed from Mexico on the harmful and beneficial values of each weed so that decisions can be made that are in the best interest of both countries.

INTRODUCTION

Several important weeds of rangelands occur in both northern Mexico and the southwestern United States. The possibility for biological control of some of these plants needs the careful consideration by scientists of both countries and decisions by both countries on whether and to what extent to proceed with a biological control program for each of the target weeds. The opinions and technical information is needed from Mexican scientists in ecology, botany, natural resources, rangelands, and livestock production. The objectives, philosophy, and potentialities for this project were discussed previously by DeLoach (1978, 1979, 1981, in press).

The present encroachment of brush into the rangelands of southwestern North America is the result of slow evolutionary changes throughout the vegetational history of the area and of rapid changes recently made by European man. The mesophytic, tropical forests of the Mesozoic Era gave way to large areas of savannah, grassland, and desert as the climate became more arid during the mid-Tertiary Period, ca. 25 million years ago, and the contest between herbaceous and woody species began. This contest culminated during the last 15,000 years with the retreat of the Wisconsin glacier and the continuation of a general drying trend, followed by the extinction of many species of large and small animals and the appearance of man (Smeins 1983).

Fire has been an important factor in the development of terrestrial vegetation, as is evidenced by the fossil record and by the occurrence of many fire-adapted species. Fire may or may not have created the grasslands but it almost certainly had a major influence on their character. Fire frequency varies from 2 to 25 years for most forested areas in dry climates and probably was at least that frequent in semiarid grasslands (Komarek 1972, Smeins 1983).

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[1] Paper presented at the Symposium on Management and Utilization of Arid Land Plants. [Saltillo, Mexico, February 18-22, 1985].

[2] C. Jack DeLoach and Paul E. Boldt are Research Entomologists, Hyrum B. Johnson is Research Plant Ecologist, and James P. Cuda is Post Doctoral Entomologist at the Grassland, Soil and Water Research Laboratory, U.S. Dept. of Agric., Agric. Res. Serv., Temple, Tex.; Hugo A. Cordo is Officer in Charge, Biological Control Laboratory, U.S. Dept. Agric., Agric. Res. Serv., Hurlingham, Argentina.

During the last 150 years in the U.S., the former grasslands have been rapidly invaded by brush in response to the introduction of grazing livestock by European man. This has caused a great reduction in the forage available for livestock grazing, and it has triggered large scale soil erosion and reduced soil water and stream flow (Humphrey 1958, Buffington and Herbel 1965, Harris 1966, York and Dick-Peddie 1969). This process began in Mexico perhaps 250 to 300 years ago. The greatest change has been the local invasion of native shrubs and herbaceous plants that are unpalatable or poisonous to livestock. None of these species have notably increased their geographic range but they have increased greatly in density (Johnston 1963, Inglis 1962).

The major causes of this recent "brush problem" in rangelands are thought to be overgrazing, spread of woody plant seed by livestock, reduced range fires, and reduced competition of grasses with woody plants, especially during seedling establishment. All of these factors are interrelated. Overgrazing reduces the grass cover below the level where it can carry a fire and weakens grasses so they are more damaged by periodic droughts than are shrubs (Bogusch 1952, Humphrey 1963, Wright and Bailey 1982). Mesquite and certain other large-seeded trees probably developed a strategy of survival based on seed dispersal by large herbivores that previously were abundant in both North and South America and became extinct about 10,000 years ago. These plants were not able to exploit this strategy again until European man introduced horses and cattle (Janzen and Martin 1982, DeLoach, in press).

Since the cause of the recent shrub invasion of grasslands is improper management of grazing livestock, one might suppose that proper management would correct the problem. However, in several experiments where plots were protected from grazing for periods of from 5 to 70 years, invasion by mesquite continued (Parker and Martin 1952, Smith and Schmutz 1975, Meyer and Bovey 1982). Apparently, shrubs must first be removed before much improvement can be made in forage production.

Livestock producers have been fighting shrub and poisonous plant invasion for many years. Mechanical controls such as hand grubbing, bulldozing, and root plowing were effective (Scifres et al. 1973, Scifres 1980) but in the United States are now too expensive to use except in small areas because of increased labor, machinery, and fuel costs. Herbicides such as 2,4,5-T have been used (Herbel et al. 1983) but are only marginally economical and do not always give good control.

BIOLOGICAL CONTROL OF WEEDS

Biological control is a different approach that has been used successfully in several areas of the world since the 1860's (Huffaker 1959; Freeman 1978; DelFosse 1981, 1985; Templeton 1982). It is not appropriate for all types of weeds but in those cases where biological control can be used it is highly effective, it gives permanent control (Huffaker 1959), and it is very low cost (Andres 1977, Harris 1979). The approach is to use insects, plant pathogens, or other organisms to control weeds. The objective is not to eradicate a weed species but to reduce it to a pest of lesser or of no economic importance (Huffaker 1959).

Major Approaches

Introduction of Foreign Control Agents

Introduction has been used to control many serious weeds in several countries of the world (Huffaker 1959, Goeden 1978, Julien 1982, Kelleher and Hulme 1984). DeBach (1974) reported that in the past 80 years 41 projects had been attempted worldwide, of which 75% had achieved a measurable degree of success: 8 were completely successful (no further control needed), 9 gave substantial, and 14 gave partial control. Until 1980, biological control by the introduction of exotic organisms had been tried against 86 weed species using 192 organisms (Julien 1982).

The approach is to find organisms (usually insects), near the center of origin or within the natural distribution of the weed that are capable of reducing weed populations (Huffaker 1959, Sands and Harley 1980, Wapshere 1980, Goeden 1983, Harris 1984). These insects then are tested in the overseas location, usually followed by further testing in quarantine in the country with the weed problem, to insure that they do not harm other plant species (Zwölfer and Harris 1971). Finally, the insects are released in the field and the results evaluated (Huffaker 1959, Wapshere 1975). The insects need to be released at only one or a few sites from which they reproduce and spread on their own and actively seek out the weed. The only cost is that of the research. The individual farmer or rancher has no cost.

The entire testing and release process is under careful review by all parties that might be affected including those of neighboring countries. Proposals from the United States are currently reviewed by the joint Working Group on Biological Control of Weeds of the U.S. Department of Agriculture and the U.S. Department of the Interior (Klingman and Coulson 1982, 1983). Prior to making their recommendation to the Animal and Plant Health Inspection Service (APHIS) of the USDA, the Working Group requests an opinion from Mexican and Canadian officials. In Mexico, these inquiries are sent to 1) Instituto Nacional de Investigaciones Agricolas, 192

San Luis Potosi, Mexico D.F., and to 2) Direccion General de Sanidad Vegetal, Guillermo Perez Valenzuela 127, Coyoacan 21, Mexico D.F.

Augmentation of Present Control Agents

Recently a different approach to bio-control of weeds has been proposed, that of augmenting the effectiveness of the phytophagous organisms already present in an area, whether native or previously introduced. Frick (1974) reviewed the various methods of augmentation that have been used. These methods include modifying the agro-ecosystem to the disadvantage of the weed, such as careful grazing management to increase competing vegetation. Also, methods of increasing the number of biotic suppressants attacking the weed have been used. These include distributing insects from areas of surplus or from laboratory colonies grown on host plants or artificial diets, producing an inundative effect by using plant pathogens as "bio-herbicides," and using insecticides to reduce the parasites or predators that attack the bio-control agent (Frick 1974).

Recently, Frick and Chandler (1978) mass released the moth, Bactra verutana, from laboratory colonies to control Cyperus rotundus in cotton fields in Mississippi, USA. Releases of 5 larvae per weed shoot 3 to 5 times during the early growing season provided effective control that resulted in a normal yield of cotton. However, the cost of mass rearing so many insects would not be competitive in cost with commercially available chemical herbicides; in addition, large rearing facilities and an intricate distribution system would be required. This method appears practical only for very high value crops such as vegetables and flowers or for hobby gardeners where economics may be secondary to esthetic or environmental goals. However, augmentation might be more practical in Mexico, where labor costs less and herbicides cost more, than in the U.S.A.

Plant pathogens also have been used to control weeds in crops (Templeton 1982). For example, in the southern United States, integrated control systems have been developed to control three weeds in rice fields and certain weeds of cotton and soybean fields using naturally occurring plant pathogens as bio-herbicides (Smith 1982). The cost of augmentation is dependent on the area treated and the duration of the treatment. Treatments must be applied to every infested hectare to be controlled and the treatment must be applied periodically, usually at least once a year. The reason is that the treatments probably will increase the population of these insects for only a short time. The native insects are always present at populations that vary from place to place and from year to year in response to local variations in temperature, rainfall, and their own natural enemies. Without augmentation, the amount of control produced at present is about all that can be expected.

In rangelands, most methods of control by augmentation appear to be too expensive because the production per unit area is very low. Rearing sufficient numbers of insects to control weeds on 6 to 20 ha to produce 1 cow per year cannot be economical to the rancher. Plant pathogens are much cheaper to mass rear than insects but still may be too expensive for controlling weeds in rangelands because of application costs.

Ranchers who hear of biological control of weeds by using insects frequently propose that researchers should increase the effectiveness of a variety of native insect species that they have observed damaging the weed at certain times. They reason that with sufficient research these native insects could be made effective every year and in all locations. Technically, they may be correct. However, the methods that could be used are expensive; also, the theory of density dependency between insects and their parasitoids and pathogens states that the more insects we release the higher will be the percent mortality of these insects from their natural enemies. The point of diminishing effectiveness would probably be reached long before the weed was controlled.

Comparison of Control Methods

Herbicides.--The greatest advantage of herbicides is their broad spectrum and effectiveness against many weed species. One application will often control all, or most, of the weeds in a particular agricultural system; also, application can be limited to a given area. Cost is dependent on the area treated and the duration of the treatment. Total cost increases as more area is treated. Cost per hectare decreases to a point as more efficiency is gained through mass production and mass distribution (fig. 1). Herbicides are often too expensive for areas of low economic return such as rangelands, since the entire affected area must be treated periodically.

Biological Control.--Biological control, both by augmentation and introduction, has the advantage of being very species specific and of not harming non-target species. It causes no chemical pollution of the environment and, sometimes, it can control species difficult to control by other methods. Because of its high specificity, it is most useful in areas where only one weed species causes most of the damage. A major restriction is that we cannot find insects suitable for controlling every weed.

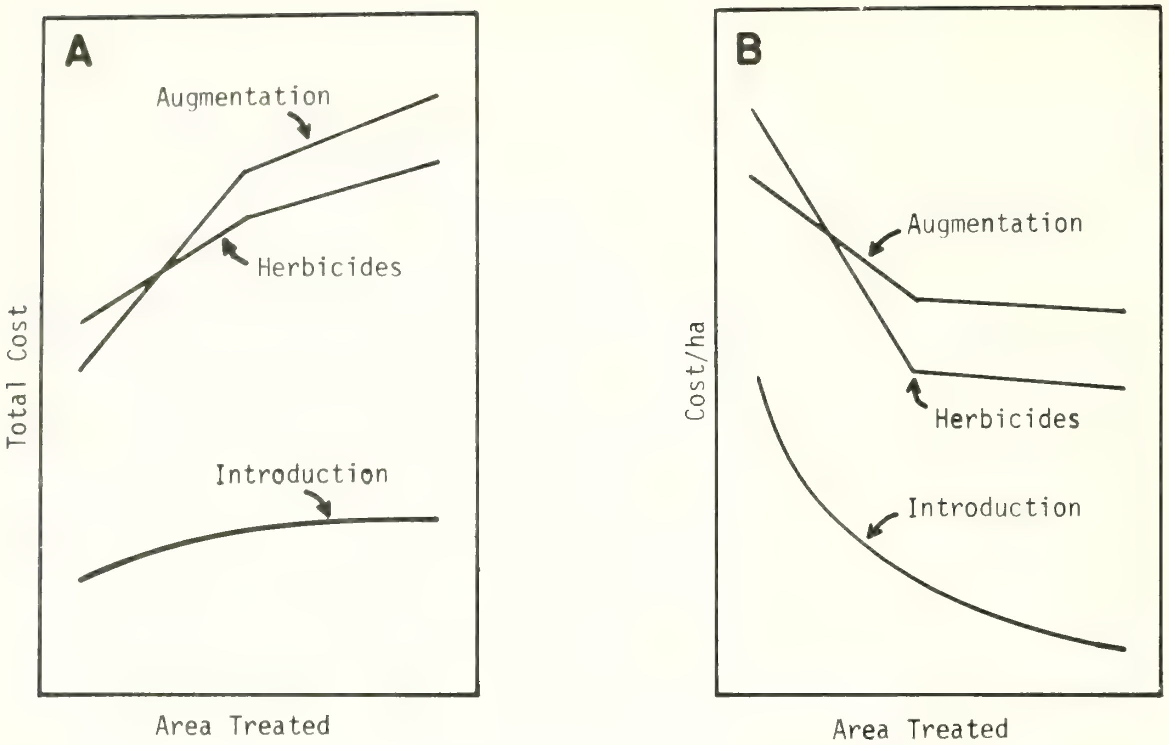

Figure 1.--Comparison of relative cost of herbicides and biological control by augmentation or introduction with increasingly larger areas treated: A) total cost of control, B) cost per hectare.

The greatest advantages of augmentation over introduction are that it is effective only in areas where applied and so does not damage beneficial uses of the plant; also, its effect can be ended simply by discontinuing application. It is similar to herbicide use in that the entire affected area must be treated at repeated intervals and so cost is dependent on the area treated and the duration of the treatments. Total cost and cost per hectare may be greater, or less, than herbicides, but the trend is the same (fig. 1). Augmentation is unlikely to be economical in areas of low economic return such as rangelands.

The greatest advantages of introduction over other methods are that control is permanent and the cost is independent of the area treated. The cost of a program is only that of the research and distribution of the organisms, and the individual farmer or rancher pays nothing. Research costs for controlling one weed species are about $1-2 million in the U.S., or ca. 15 scientist years (Andres 1977). Total cost of a program remains constant regardless of the area treated, but cost/ha decreases as larger areas are controlled, and decreases still more with each added year of control (fig. 1). This makes the method very applicable to areas of low economic return, such as rangelands. A disadvantages of introduction is that the control organisms are likely to attack the weed species in areas where it has beneficial value.

Considerations in Using Biological Control

Control of Native Plants.--Most of the more serious weeds of southwestern rangelands are native species. Biological control of native weeds may be more difficult than for introduced weeds because:

1) Control organisms that are sufficiently host specific for introduction may be more difficult to find.

2) A native weed is more likely to be closely related to beneficial native species, making host specificity of control organisms more critical.

3) Most niches through which a control organism could attack the weed may already be occupied.

4) The weed species, and its close relatives, are more likely to be of value in the ecosystem.

The classical approach to biological control of introduced weeds has been to introduce the insects (or plant pathogens) from near the site of origin of the weed that naturally control its populations there. With native weeds, this approach obviously cannot be applied; the insects that evolved with the weed are already here and produce the degree of control we now see.

However, several of our native weeds are from genera that have species native in other areas of the world, especially in southern South America. We propose to introduce natural enemies, especially insects, from South America to control certain weeds. The principle criteria for success are that the weed should not have overriding beneficial values and that natural enemies can be found that damage the plant but yet are sufficiently host specific not to damage beneficial plants if introduced here. Several of the major weeds of southwestern U.S. and northern Mexico have reasonably good potential for successful control.

Some biological control workers have expressed concern that control of native weeds might trigger some unknown and unwanted reaction in the ecosystem that might be of serious consequence (Andres 1981). However, one of us (Johnson, in press) examined (from the perspective of plant ecology) the effects of species removal on the ecosystem. He found little or no evidence in past catastrophic reductions of dominant native species, in past biological control successes, or in ecological theory to indicate that significant harm might occur to ecosystem function. Also, in all cases of major successes in biological control throughout the world, low populations of the weed remain; no weed nor non-target plant species has been pushed near an endangered status.

Conflicts of Interest.--A plant that causes damage in one situation, for example on rangelands used for livestock production, may provide benefits in other situations, such as for ornamental shade trees, for human food, emergency livestock grazing, or for wildlife food and cover. Conflicts of interest between groups who regard plants differently is one of the major problems that must be resolved before beginning a project on biological control. In this paper, we present briefly the harmful aspects, beneficial values, ecological values, and the potential for successful biological control of several target weeds. More detailed analyses of each weed are either being published (DeLoach, in press) or are in preparation. The purpose is to provide a basis for discussion between groups with conflicting interests so that decisions eventually can be made about whether or not to attempt biological control of each candidate weed species.

Proposed Species for Biological Control

We have attempted to prepare a list of priority weeds for biological control research. The criteria for selection were, 1) The weed causes sufficient damage to justify the cost of a control project; 2) The weed species, or other species of the weed genus, grows as a native plant in some other area of the world where we would have a chance of finding control organisms; 3) Neither the weed species, nor its close relatives, are of overriding beneficial value; 4) Control organisms are known that appear capable of controlling weed populations.

Gutierrezia (Snakeweed, Escobilla)

The genus Gutierrezia (Compositae: Astereae) consists of annual and perennial subshrubs that originated in southwestern North America, probably in montane habitats of the southern Sierra Madre Occidental of Mexico, possibly during the Miocene (Lane 1980); she recognized 16 species in North America (Lane 1985). The genus subsequently spread to southern South America, probably by long-distance dispersion by birds, where 11 species subsequently evolved; all are higher polyploids of the North American species and all are perennials (Solbrig 1966). The genera Gutierrezia, Xanthocephalum, Amphiachrys, Gymnosperma, and Grindelia are all closely related (Lane 1982).

The most serious weedy species are the perennials, Gutierrezia sarothrae and G. microcephala, which together infest 58 million ha in the U.S. (Platt 1959) and more in Mexico; both are toxic to cattle. The annuals G. sphaerocephala, G. texana, and the closely related Amphiachrys dracunculoides, are also serious weeds but are not toxic.

Gutierrezia was an uncommon plant 150 years ago and its recent great increase in density was probably caused by overgrazing. The greatest damage occurs in New Mexico, Chihuahua, and Texas; over vast areas it is now the dominant plant, often with little grass remaining (Humphrey 1958). It is also toxic and in affected herds of cattle, 10-60% of the calf crop may be born dead, weak, or premature (Dollahite and Anthony 1956). The annual species interfere with grazing, causing reduced calf growth rates.

Gutierrezia has very little beneficial value either for commercial utilization or for wild mammals and birds (Martin et al. 1951).

We have found several root-boring insects in Argentina that severely damage the tap roots (Cordo and DeLoach, in press b). The most important are Heilipodus ventralis (Coleoptera: Curculionidae), Carmenta haematica (Lepidoptera: Sesiidae), and Dactylozodes alternans, D. okea, and Agrilus leucostictus (Coleoptera: Buprestidae). In Argentina, one of us (Cordo, unpublished data) found that H. ventralis attacks Gutierrezia and Grindelia chiloensis about equally and attacks Baccharis slightly. Testing is continuing in quarantine at Temple, TX, and testing is now underway in Argentina on C. haematica.

Baccharis (Seepwillow, Jara)

Baccharis (Compositae: Astereae) is a genus of ca. 400 dioecious species native only in the Western Hemisphere; the center of origin is South America (Cuatrecasas 1967, Barroso 1976). About 27 shrubby species occur in Mexico and 21 in the U.S. (Haseler 1969, Shelter and Skog 1978).

Baccharis infested 81,720 ha in Texas in 1973 (unpubl. records, USDA Soil Conserv. Serv., Temple, TX); it occupies additional areas in New Mexico, Arizona, southern California, and northern Mexico. Baccharis species are problem weeds of rangelands, pastures, parks, recreational areas, and flood plains of streams. Baccharis species are unpalatable to livestock and form dense thickets as phreatophytes along streams, crowding out valuable forage plants (Parker 1972). Baccharis species produce large amounts of seed, rapidly invade abandoned cultivated fields and other disturbed areas, and resprout if cut off above ground. Control with herbicides is generally too expensive relative to the low value per unit area of rangelands. Problems caused by the 3 most important weedy Baccharis species are as follows:

Baccharis salicifolia (=B. glutinosa) is one of the dominant phreatophytes along streams and flood plains, reservoirs, and irrigation and drainage canals. The plants cause increased sediment deposits in streams and reduced water flow, and thus contribute to flooding, increased canal maintenance costs, and loss of enormous quantities of soil water in areas where water is scarce and needed for other purposes (Timmons 1959, Parker 1972). In 1953, undesirable phreatophytes as a group covered 4,453,000 ha of bottomland in 14 western U.S. states and used nearly 20.6 million megaliters of water (16.7 million acre feet) (Fletcher and Elmendorf 1955).

Baccharis halimifolia is toxic to some animals (Duncan et al. 1957) and is probably a cause of hayfever in humans (Wodehouse 1971). It rapidly invades areas of recent soil disturbance and is common along roadsides, along drainage ditches, in abandoned cultivated fields, etc. (Haseler 1969).

Baccharis neglecta has become a management problem in rangelands and pastures in the southern half of Texas. It rapidly invades productive disturbed land and grows rapidly, forming dense stands (Mutz et al. 1979, Scifres 1980).

Baccharis species have few beneficial values and none of these values appear to be of widespread importance. Baccharis halimifolia is used as a garden shrub or hedge in Florida because of its hardiness, freedom from disease, attractive fall flowering, and resistance to salt spray (Haseler 1969). Baccharis salicifolia is sometimes used for erosion control (Vines 1960) although Fletcher and Elmendorf (1955) suggested the use of other plants that use less water. All 3 species are locally considered to be good honey plants because they flower in late summer when few other plants are in flower. The amount of honey produced varies greatly from year to year (Pellett 1930). The only species used commercially in the U.S. is B. pilularis, a low-growing shrub used in California around houses and on roadbanks as a ground cover. It maintains a bright green color during the dry season, forms a dense mat that excludes most weeds, and withstands full exposure to the summer sun (Munz 1949).

Baccharis has little or no value for wildlife except for the cover it provides and possibly as nesting sites for songbirds (Tarver et al. 1979). It is not listed as a food for any wildlife by Martin et al. (1951).

Several insects have been found attacking Baccharis in Brazil (McFadyen 1979) and Argentina (H. A. Cordo, unpubl. data) and some of these have been released in Australia for biological control of the introduced B. halimifolia, the only species that occurs there. Three species of insects are currently under investigation for biological control by one of us (Boldt) in the Insect Quarantine Facility at Temple, TX.

Megacyllene mellyi (Coleoptera: Cerambycidae) is a stem borer from Brazil that requires living tissue for development. The larvae tunnel under the bark for about one month before feeding toward the center of the stem. Small plants have been killed by as few as 2 larvae tunneling in the base (McFadyen 1979). This beetle was released in the field in Australia in 1978 and is now well established there.

Rhopalomyia californica (Diptera: Cecidomyiidae), native in California, produces galls on the growing tips of the branches. Many galls can severely stunt the plant and retard growth. This gall midge was released in Australia in 1982 where it is increasing rapidly. It appears capable, with more time, of providing good control there (McFadyen, in press).

Anacassis spp. (Coleoptera: Chrysomelidae) are native in Argentina and Brazil. They are leaf feeders in both the larval and adult stages. These insects are multivoltine and occur in large numbers in Argentina. Anacassis fuscata was released in Australia but has not provided much control of B. halimifolia there. Preliminary tests at Temple, TX, show that they are very host specific and will probably attack only B. salicifolia to any significant extent.

Larrea (Creosotebush, Gobernadora)

The genus Larrea (Zygophyllaceae) originated in Argentina and spread to North America, probably by birds, as recently as 10,000 to 14,000 years ago. Only one species occurs in north America, L. tridentata, which is very close taxonomically to the Argentine L. divaricata (Hunziker et al. 1977).

Larrea occupies an estimated 19 million ha in the U.S. (Platt 1959) and over 10 million ha in northern Mexico (Gonzáles 1971). It has spread greatly in the last 150 years into previous grasslands, apparently as a result of overgrazing by livestock (York and Dick-Peddie 1969). In the arid areas where it is abundant, it is now the dominant species over large areas.

In many areas, very little grass remains. Recent studies in New Mexico have shown that seriously denuded areas can be returned rapidly to good stands of native grasses if Larrea is killed with herbicides and the grass is not overgrazed (Melgoza et al. 1984). The foliage of Larrea appears not to be toxic but is not palatable to livestock.

Larrea has been extensively investigated in Mexico for possible industrial utilization (Campos-Lopez et al. 1979). Large amounts of the phenolic compound nordihydroguaiaretic acid (NDGA) are present in the resin on the external surface of the leaves and stems. NDGA is an antioxidant that has been used to retard rancidity of food products (Oliveto 1972). However, rats fed NDGA at 3% of the diet developed kidney cysts and it was banned as an additive in food by the U.S. Food and Drug Administration (Timmerman 1977). NDGA is also an effective antioxidant to stabilize rubber, perfume oils, and other products. It has fungicidal activity, inhibits enzyme systems, and has some anti-tumor activity. Tea made from the plant has long been used as a folk medicine in both North and South America.

A total of 28 species of small mammals were found in Larrea communities in Arizona, from 6 to 13 species in each community, but only a few were very abundant, including Dipodomys merriami, Perognathus longimembris, P. penicillatus, and Lepus californicus. Also, 9 species of lizards were found (Mares and Hulse 1977, Blair 1979). None of these species appeared to be strongly dependent on Larrea. Reptiles, amphibians, and most other terrestrial vertebrates usually are not intimately associated with a specific plant taxon but sometimes are restricted to a specific plant community (Mares and Hulse 1977).

Fewer insect species appear to be associated with Larrea than with some other plants of semiarid areas such as Prosopis. Schultz et al. (1977) found 22 herbivorous insect associates of Larrea near Silver Bell, Arizona, 18 of which were monophagous. However, in a later paper discussing the same insects, Schultz (1979) listed only 7 species as monophagous. Hurd and Linsley (1975a) found 79 species of insects other than bees on Larrea in the southwestern U.S., 44 of which were abundant or common, but only one species of grasshopper and a few geometrid larvae were mentioned as possibly being restricted to Larrea. They also found 90 species of bees associated with Larrea, 22 of them oligoleges (Hurd and Linsley 1975b).

In Argentina, the insect associates also are not numerous but a few species occur there that appear to be host specific and might be suitable for introduction for biological control. Schultz et al. (1977) listed 19 herbivorous insects from L. cuneifolia near Andalgala, Catamarca, Argentina, 5 of which were monophagous, and 3 that were oligophagous and fed only on Zygophyllaceae. The most damaging was the oligophagous grasshopper, Astroma quadrilobatum. Also, 2 meloid beetles fed on flowers, the larvae of 2 buprestid beetles tunneled in the stems (Schultz et al. 1977, Schultz 1979), and scale insects fed on the stems and leaves (Teran 1973). A fossorial rodent, the tuco-tuco (Ctenomys fulvus), fed extensively on the stems and killed many plants in Argentina (Mares and Hulse 1977, Blair 1979); however, its food preferences and the effects of its burrows in rangelands would have to be carefully studied before considering it for introduction.

Tamarix (Saltcedar, Pinabete)

Tamarix (Tamaraceae) is a genus of ca. 54 species native from North Africa and the Mediterranean area to Pakistan (Baum 1978, Zohary 1972). About 7 species were introduced into the U.S. in the early 1800's as ornamentals. They have escaped cultivation and are rapidly invading the floodplains of southwestern streams. Tamarix spp. form dense thickets that use large amounts of water in this semiarid area where water is scarce, they contribute to sedimentation and flooding of the streams, and they replace the native vegetation (Watts et al. 1977, Van Hylckama 1970, Blackburn et al. 1982).

Tamarix has beneficial value as habitat, but not food, for the white-winged dove, Zenaida asiatica (Scudday et al. 1980), which occurs from southwestern Texas and southern New Mexico and Arizona southward through Mexico to Guatemala. In western Texas, saltcedar communities supported fewer bird species than did native plant communities (Anderson et al. 1977). In Mexico, the white-winged dove is thought not to be particularly associated with saltcedar; the areas with the highest dove populations have but little saltcedar (Lucio Rodriguez, Dept. Recursos Naturales, Univ. Autonoma Agraria "Antonio Narro," Saltillo, Coah., pers. commun.). Also, the flowers are an important source of nectar for honey production. One species, Tamarix aphylla, grows to a large size and is used as an ornamental shade tree in the southwestern U.S. and northern Mexico; it is also used as a windbreak in some areas.

Watts et al. (1977) collected 159 species of insects and one mite from Tamarix in New Mexico. Most of these species occurred only in very low numbers, with little evidence of feeding, and damage occurred only in isolated instances. Two alien insect species, a leafhopper Opsius stactogalus and a scale Chionaspis etrusca, were often abundant and damaged the plant.

The insects attacking Tamarix in its native range have been much studied. Gerling and Kugler (1973) listed 115 species of insects and 4 mites from Israel, Turkey, Iran, and Pakistan. Lozovoi (1961) listed 52 insect species from Georgia, U.S.S.R.; Zocchi (1971) listed 92 species from Italy, including 42 monophagous ones; and Pemberton and Hoover (1980) listed 26 species from Turkey. Gerling and Kugler (1973) studied the biology of 24 species and concluded that 13 species would be good candidates for introduction. Species such as *Ornativalva versicolor* (Gelechiidae), *Cryptocephalus fulgurans* (Chrysomelidae), *Naiacoccus minor* (Pseudococcidae), *Dasyneura tamaricina* (Cecidomyiidae), *Agdistis tamaricis* (Pterophoridae), and possibly *Lepidogma* sp. (Pyralidae) attack the foliage of other species of *Tamarix*, but do not attack *T. aphylla*, and therefore would not harm ornamental *T. aphylla* plants or flowers used for honey production. Other insects also attacked *T. aphylla*, such as *Sterapsis squamosa* (Buprestidae), *Semiothisa aestimaria* (Geometridae), *Oxyrrhachis versicolor* (Cercopidae), and *Opsius* spp. (Cicadillidae). Other insects damage the flowers, such as *Coniatus* spp. and *Corimalia* spp. (Curculionidae), and *Crastina tamaricina* (Psylloidea).

We propose that a series of insects should be introduced from Asia in an attempt to obtain ca. 50% reduction in stands of *Tamarix*. At that time a reevaluation should be made to determine the effect on the dove-hunting and honey industries. A 50-80% reduction in stands would allow the reestablishment of much native vegetation, would conserve large amounts of water, and would cause little harm to the beneficial uses of the plant. Insects would be selected that do not attack or that caused only minimal harm to *T. aphylla* and that do not directly attack the flowers.

Prosopis (Mesquite)

The genus *Prosopis* (Leguminosae) underwent its greatest speciation in southern South America, where 33 species occur; 9 species are native in the U.S. and Mexico (Burkart 1976). The genus apparently spread to North America about 25-36 million years ago, in the mid-Oligocene (Smeins 1983). Two species, *P. glandulosa* and *P. velutina*, are probably the most damaging of all weeds in rangelands of the southwestern U.S. During the last 150 years, mesquite has invaded much of the former grasslands and has increased greatly in density, probably because of overgrazing, spreading of seed by livestock, and reduction in range fires. Mesquite causes damage by reducing forage production, increasing the cost of managing livestock, and reducing water available for agriculture, industry, and urban use (Smith and Rechenthin 1964, Rechenthin and Smith 1967, Fisher 1977, Scifres 1980). DeLoach (in press) estimated that mesquite causes direct losses to the livestock industry of $200 to 500 million annually in the U.S. plus an unknown amount in Mexico; the amount of damage was probably 20-30 times greater than all present beneficial uses.

Control of mesquite by mechanical and chemical methods is expensive and only marginally effective. The most economical herbicide was 2,4,5-T; it had to be applied ca. once every 8 years and was cost-effective only on the denser stands on the more productive soils (Dahl et al. 1978, Whitson and Scifres 1979). It has recently been prohibited for use. The new herbicide, clopyralid, promises to be more effective than 2,4,5-T (Jacoby et al. 1981) but will also be more expensive and relatively ineffective on associated weedy species.

Mesquite also has many beneficial uses (Parker 1982, DeLoach, in press). It is widely used throughout central Texas and southern Arizona as an ornamental shade tree for which its one-time value is approximately $100 million in Texas. It is currently popular for barbecue wood and firewood for heating. It is an excellent source of nectar for honey production, and the legumes (beans) are eaten by livestock. In Mexico, the beans are collected, ground, and used in livestock feed, and the wood is used for firewood, farm construction, flooring, etc., although this usage has declined greatly in recent years because most of the larger trees have been cut (Gómez Lorence et al. 1970).

Other proposed uses for mesquite include production of paper, gums, chemicals and medicines, the processed wood for livestock feed, and the beans for human food. Production of these products from mesquite does not seem economically competitive with production from other raw materials that are plentifully available (Parker 1982, DeLoach, in press).

For a native plant that is so abundant over a large area of southwestern North America, mesquite has surprisingly little value for native mammals and birds. Mares and Hulse (1977) observed that more animals had an obligate relationship with mesquite in South America than in North America. One suspects that some species that once depended heavily on it are now extinct.

Mesquite constitutes 30-50% of the diet of jackrabbits (*Lepus* spp.), 30% of the diet of the wood rat (*Neotoma albigula*), 4-13% of the diet of the pocket mouse (*Perognathus* sp.), 4-11% of the diet of kangaroo rats (*Dipodomys* spp.), and 10-25% of the diet of the Gambel quail (*Lophortyx gambelii*). Mesquite was of little importance in the diets of other native mammals and birds (Martin et al. 1951). A drastic reduction of mesquite density would probably reduce populations of these animals somewhat; however, most of these are so abundant now that they cause damage to some rangelands and some reduction in their population might be advantageous. The Gambel quail is the only one of these species for which a reduction in its population would be undesirable; however, the amount of reduction caused by the degree of control we are likely to achieve probably would be relatively unimportant to quail populations (DeLoach, in press).

The cultivation of high-biomass producing strains of mesquite has been proposed as an energy source for production of electricity or petrochemicals (Felker 1984). Also, Gilbert (in press) speculated that nitrogen fixation by mesquite might be of great value in natural ecosystems and in rangelands. Neither of these hypotheses have been demonstrated in the field. DeLoach (in press) suggested that nitrogen fixation may be inconsequential in upland areas and that sufficient biomass for commercial electrical production probably can be realized only with irrigation, in areas with a high water table, or in limited upland areas of highest rainfall.

Ward et al. (1977) listed 657 species of phytophagous insects collected from mesquite in the U.S. and Mexico. Cordo and DeLoach (in press a) reported 394 species of insects collected from mesquite in Argentina and Paraguay, 15 of which are cosmopolitan and also occur in North America. They concluded that 38 species were reasonably good candidates for further study for introduction into North America for biological control; these included insects that attacked the seed, flowers, buds, foliage, limbs, and trunks. Some of these insects caused extensive damage in Argentina and might be even more damaging if freed of their own natural enemies before being introduced here.

We tentatively propose that seed, legume, and flower feeding insects be introduced for biological control. Huffaker (1959) suggested that seed-feeding insects of long-lived perennial plants were unlikely to be effective biocontrol agents. However, Neser and Kluge (in press) recently reported that the shrub, Hakea sericea, was being controlled by a seed-feeding weevil in South Africa. Harley (in press) discussed several projects where seed-feeding and flower-feeding insects are being used for control of woody plants. If effective, these insects that would reduce the reproductive capacity of mesquite would slow or halt its continued spread without harming its beneficial uses for shade trees, firewood, or energy production.

Flourensia (Tarbush, Hojasen)

Flourensia is a genus of 31 species of desert shrubs in the family Compositae (tribe Heliantheae), that probably originated in North America. Today, 13 species are found in North America (Mexico and adjacent areas of the U.S.) and 18 in South America (mostly in Argentina and Peru) (Dillon 1984). One species, F. cernua, is a weed in rangelands in the southwestern U.S. and northern Mexico and the acreage infested is increasing (Buffington and Herbel 1965). Its effect in rangelands is similar to that of Larrea. It grows intermixed with Larrea and stands are often invaded by Larrea, but it reaches its best development on heavy soils that receive some extra water (Gardner 1951). The ripe fruit is poisonous to sheep and goats (Kingsbury 1964). Flourensia cernua has no known important beneficial values to man or in plant and animal communities.

In our rather limited collections in the USA, we have found few insect species on the plant, although buprestid beetles occasionally bore in the stems and roots. In Argentina, we have found rather numerous cerambycid and lepidopterous larvae boring in the crown and stems and weevils that feed on the foliage (H. A. Cordo and C. J. DeLoach, unpubl. data). Additional exploration for and testing of insects is needed in Argentina before the potential for control can be properly evaluated.

Hymenoxys (Bitterweed, Hierba Amarga)

Hymenoxys (Compositae: Helenieae) is a genus of about 28 species found only in the Western Hemisphere. The center of origin is southwestern North America. The genus spread to southern South America probably in the late Tertiary or Quaternary Periods and 4 annual species are native there (Sanderson 1975).

Two species are poisonous to livestock, especially to sheep. The perennial H. Richardsonii is a pest mostly in Arizona, New Mexico and Colorado, though it occurs to southern Canada. The winter annual H. odorata occurs from northern Mexico to Kansas but is a pest mostly in the Edwards Plateau of Texas. It becomes abundant only in occasional years when the seed germinate in the fall in response to fall rains. Most poisoning occurs in early spring when bitterweed is one of the few green plants present. In most years it grows only in wet depressions (playas) but spreads over wide areas in years of favorable rainfall. In the early 1930's more than half of many flocks died from bitterweed poisoning and heavy losses occurred again in the 1950's (Parker 1936, Cory 1951, Rowe et al. 1973). Annual losses in Texas were estimated at $3,570,000 (Jaggi 1962). The nectar is very bitter and a small amount collected by bees can ruin a honey crop. Hymenovin from bitterweed is mutagenic to some organisms; MacGregor (1977) discussed the possible dangers of livestock transmitting mutagenic compounds to humans through milk or meat.

Hymenoxys has very little beneficial value. Five species of the genus are minor ornamentals (Bailey and Bailey 1976), some of the chemicals in it have anti-tumor activity, and the latex was used as a minor source of rubber during World War II. Wildlife do not use any species of the genus as food (Martin et al. 1951).

We have found a few insects in Argentina that may hold promise for biological control. The most promising are an unidentified species of Diptera whose larvae feed in the petiole and crown and two species of Lepidoptera whose larvae feed in the crown and roots.

Salsola spp. (Russian Thistle, Tumbleweed)

Salsola (Chenopodiaceae) is a halophytic, desert genus of ca. 150 species of cosmopolitan distribution. Two species of Russian thistle are present in North America, both introduced from Asia. Salsola iberica (=S. pestifer or S. kali) is more prominant at the higher elevations and latitudes of the USA and S. paulsenii is more prominent at lower elevations of the southwestern area (Beatley 1973). Russian thistle was introduced into the USA in 1873 as a contaminant of flax seed that was planted in South Dakota. It has since spread over most of the central and western USA and northern Mexico.

Russian thistle infests 41.3 million ha in the western USA (Platt 1959). It occurs mostly in disturbed areas such as highway rights-of-way and abandoned cultivated fields but seldom invades rangelands. At maturity, the plant breaks off at the base and rolls in the wind. The dead plants pile up along fences and buildings creating a fire hazard, interfering with fence maintenance, and causing a nuisance. Older plants are unpalatable to livestock and physically inhibit grazing although they are not poisonous. Russian thistle is the primary host of the beet leafhopper, Circulifera tenellus, which is the vector of "curly top" virus of sugar beets, tomatoes, and curcubits (Lawson and Piemeisel 1943) and it is an important weed in winter wheat.

Russian thistle has very little beneficial value. Young plants are sometimes grazed by livestock and it has been proposed as a drought resistant forage plant and a source of biomass for fuel. During the drought of the 1930's, 400,000 tons were harvested for hay in western Kansas in 1934 (Hageman et al. 1978).

The seeds of Salsola are eaten by 8 species of birds. The foliage and seeds are eaten by 11 species of small mammals and by deer, elk, and antelope; however, it constitutes as much as 10-25% of the diet of only the prairie dog (Cynomys sp.) (Martin et al. 1951).

Many species of insects have been found attacking the plant within its native range in the USSR (L. A. Andres, pers. commun.), in Pakistan (Baloch et al. 1975), and in Turkey (Goeden 1973). However, only a few of these were host specific. Two species of moths (Coleophoridae) have been released in the USA, Coleophora parthenica that tunnels in the pith of the stems and C. klimeschiella that feeds on the foliage (Hawkes and Mayfield 1978). Coleophora parthenica has become well established and abundant but causes little damage to the plant (Pemberton 1980); C. klimeschiella also causes little damage (L. A.Andres, pers. commun.). A third species, Heterographis monostictella (Lepidoptera: Phycitidae) appeared host specific in the field but completed its development on beet in laboratory tests (Baloch et al. 1975).

The two insects, Coleophora parthenica and C. klimeschiella could be released in Mexico for control of Russian thistle. So far they have been ineffective in the USA, but the longer growing season in Mexico might allow them to develop additional generations each year thus producing larger populations and a greater degree of control. Additional exploration is needed in areas of the USSR and China to find additional host-specific natural enemies for introduction into North America.

Aloysia (Whitebrush, Jasmin)

Aloysia (Verbenaceae) is a genus of about 30 species that originated in southern South America and is restricted to the Western Hemisphere. Seven species occur in Mexico and the U.S. (Botta 1979, Troncoso 1974). Aloysia gratissima (=A. lycioides) is the only weedy species of importance; it is apparently native in Mexico and the southwestern U.S. but presumably evolved in Argentina and Paraguay since it also occurs naturally there.

Aloysia is a pest mainly because it competes with forage plants and forms dense thickets that make handling livestock difficult. It occupies ca. 3 million ha in the U.S. with ca. 350,000 ha in dense stands. It is a pest mostly in central and southern Texas, often on the best soils. Forage production is usually increased 2-3 times by controlling whitebrush. Rootplowing, raking, and double discing give good control but are too costly; tebuthiuron gives effective control at rates of 0.5 to 1.0 kg/ha. We estimate that direct losses to livestock production are ca $25 million annually.

Although whitebrush produces a premium, light honey, it produces a good yield only every 2 to 3 years. The Argentine A. triphylla is sometimes cultivated in the U.S. as an ornamental but A. gratissima is rarely if ever cultivated (Bailey and Bailey 1976). It is not a food plant for wildlife (Martin et al. 1951) and it is of little value as cover for deer (Inglis et al. 1978).

We have never found insects damaging the stems or roots of A. gratissima in Texas; the phytophagous insects collected from the foliage appear to be only incidentals, and we have found no pathogens. All niches for herbivorous insects appear to be unoccupied. However, the South American fauna on Aloysia is also poor, though greater than the North American. Cordo and DeLoach (in press c) collected 82 species of insects and 4 plant pathogens from Aloysia in Argentina, Paraguay, and southern Brazil.

The better candidates for introduction are a new species of rust fungus, Prospodium tumefaciens, that causes stem galls, a buprestid stem-boring beetle in the tribe Agrilini, a large cerambycid crown-boring beetle probably in the genus Calocosmus, a scale insect in the genus Cerococcus, a bark-feeding moth Timocratica sp., and a cerambycid twig girdler near the genus Arenicia (Cordo and DeLoach, in press c). Only the rust fungus caused much damage but the other species might cause more damage in North America if their own parasites were eliminated before release. Further study is needed in Argentina to determine if any of these organisms are suitable for introduction.

Other Weeds

Several other weeds of rangelands have potential for biological control but have been less investigated by us; conflicts of interest with beneficial values of some plants are too great to attempt control.

Several species of Astragalus (Leguminosae) (locoweed, yerba loca) are poisonous to livestock; losses from poisoning are estimated at $10 million annually in the U.S. and an undetermined amount in Mexico. Astragalus is a genus of ca. 1500 species, mostly of Holarctic distribution, with 368 species native in the U.S. and about 87 in southern South America. The chances of finding insects that would attack our pest species are good. We have found insects in Argentina that damage the foliage, legumes, and roots of other species of the genus. However, several native species in North America are valuable for wildlife, several are rare or endangered, and a few are cultivated as forage plants. These conflicts would have to be evaluated carefully before considering a bio-control project.

Opuntia (Cactaceae) is a genus of ca. 187 spp, all from North and South America. Benson (1982) stated that the taxonomy of the genus is in a chaotic state. He listed 43 species of subgenus Cylindropuntia in the U.S. and Mexico and 42 species in southern South America. In subgenus Opuntia (prickly pear), he listed 48 species from the U.S. and Mexico, 23 species from southern South America, and 31 species from the West Indies, northern South America, Brazil, the Galapagos Islands, or of unknown origin.

Opuntia spp. (prickly pear, nopal) infest 31 million ha in the U.S. (Platt 1959); 15 million ha of this is in Texas, 1 million ha in dense stands (Smith and Rechenthin 1964). The most serious damage is to the sheep industry in central Texas. When sheep (or other animals) eat the pads or fruit, the spines and glochids become embedded in the mouth, esophagous, and stomach, causing weight loss and sometimes death. However, Opuntia also has considerable beneficial value: the fruits and young pads (cladophylls) are used as human food, it is widely used as an ornamental, and ranchers burn off the thorns and use it for supplemental grazing during droughts. It is recognized as a valuable forage for cattle in Mexico (González 1971). Also, 44 species of wildlife use it, and it is a major part of the diets of three species (Martin et al. 1951). Many of the North American species are beneficial and some are rare.

Several insects are known in Argentina that probably would give good control if introduced, including Cactoblastis cactorum (Lepidoptera: Phycitidae) that has been introduced elsewhere for successful cactus control (Dodd 1940). The beneficial values of prickly pear appear too great to attempt biological control. However, other species of Opuntia in subgenus Cylindropuntia, such as O. imbricata (tree cholla, coyonostole) and O. leptocaulis (tasajillo) are serious pests and have little or no beneficial value. Biological control of these species perhaps could be attempted if control agents could be found that are sufficiently host specific not to attack the "pear" species or other beneficial cacti.

Juniperus (juniper or cedar, enebro) is a genus of about 70 species native throughout the Northern Hemisphere. Junipers infest 26 million ha (Platt 1959) and are among the most serious weeds of western and southwestern U.S. ranges; they are not poisonous but compete severely with forage plants (Smith and Rechenthin 1964, Scifres 1980). Junipers usually occur on poor range sites where chemical and mechanical control methods are too expensive. The native J. virginiana and possibly other species of Juniperus are alternate hosts for cedar-apple rust (Gymnosporangium juniperi-virginianae), a serious disease of fruit trees.

Several native and introduced species are widely used and valuable ornamentals, and J. virginiana is valuable for lumber for cedar chests and closets (Bailey and Bailey 1976). The weedy species of the southwestern United States are used for fenceposts and production of aromatic oils. Junipers are valuable plants for wildlife feed and cover; 44 species of birds and mammals feed on them but they are of major importance (more than 10% of the diet) for only 4 species (Martin et al. 1951). Previously, we have considered that Juniperus is too valuable to attempt biological control. In view of the severity of the damage caused, we believe the question should be re-examined. A more complete analysis of conflicts of interest should be made and surveys should be made to determine if suitable control agents exist.

Acacia farnesiana (huisache) (family Leguminosae) infests about 800,000 ha, mostly in southern Texas (Smith and Rechenthin 1964) and probably much more than this in Mexico. It forms thorn thickets on the better soils in low areas and competes with forage plants. Acacia is a large genus distributed throughout semiarid areas of the Southern Hemisphere. Huisache is valuable for firewood, farm implements, honey production (Gómez Lorence et al. 1970) and as a shade tree and occasionally as an ornamental. The conflicts of interest need to be evaluated to determine if biological control should be considered.

Drymaria (Alfombrilla) (family Caryophyllaceae) is a genus of 48 species, only 2 of whose ranges extend beyond the Americas. Two centers of speciation occur, one in Mexico where 31 species are native (7 of these extend into western USA), and one in southern South America where 17 species occur (15 in Peru, 7 in Bolivia, and 3 in Argentina). Only 4 species of the North American center occur in the South American center (Duke 1961). The annual D. pachyphylla is toxic to sheep and cattle; it occurs from southeastern Arizona, southern New Mexico, and western Texas south to western Nuevo

Leon, southern Coahuila, and eastern Durango. The perennial alfombrilla (D. arenarioides) occurs from Hidalgo and Guanajuato in central Mexico north almost to the United States border (Duke 1961; Hartman, in press). González and Martínez (1958) reported that alfombrilla was the most important toxic plant in Chihuahua and caused the death of over 1,000 cattle per year just in the north-central area of the state; however, it did not appear toxic to horses. Allison (1977) reported that it was poisonous to both cattle and sheep. Explorations are needed in the South American center of speciation to discover if natural enemies exist that could be introduced into North America for biological control.

CONCLUSIONS

Several of the more serious weeds of rangelands of the southwestern United States and northern Mexico have good potential for biological control. The introduction of insects and possibly plant pathogens from other areas of the world, principally from semiarid regions of southern South America, where other species of the weed genus are native, offer the most potential for success. Promising natural enemies have been identified on some of these weeds and a few insects are being tested at the USDA's Biological Control of Weeds Laboratory near Buenos Aires, Argentina, by one of us (Cordo). At the moment, the weeds that would seem acceptable to both the U.S. and Mexico for biological control are Gutierrezia, Baccharis, Flourensia, and several of the poisonous species. Perhaps more species can be added when the harmful, beneficial, and ecological aspects are more carefully analyzed.

Conflicts of interest between groups who regard a plant as a noxious weed and those who regard it as beneficial are a major consideration before initiating biological control programs. We are presently compiling the available information in the United States so that these conflicts can be equably and fairly considered. Then decisions can be made that are in the best overall interests of the two countries.

Most of the weeds under consideration are common to both the U.S. and to Mexico. When one considers the initiation of biological control programs, the interests of ranchers, small farmers, industry, and concern for a healthy ecosystem are of equal importance in Mexico as in the United States. So far, we have been able to gather only a little information from Mexico regarding the various aspects of these weed problems. The following types of information are needed:

1) A list of the most damaging weeds of rangelands.

2) Geographical occurrence of the weed and in which areas the greatest problems occur.

3) Estimated area (hectares) infested by each weed and density within the infested area.

4) Type of damage and estimates of economic losses caused by each weed.

5) Types of beneficial uses of each weed, both for commercial or home utilization and ecological values, and estimates of the value and importance of each.

6) References on the impact of each weed species in Mexico, especially on damage caused and beneficial, ecological, and wildlife values.

7) Opinions of Mexican scientists on whether or not biological control by introduction should be attempted for each target weed.

8) Priority listing of target weeds for biological control.

We would appreciate receiving any of this information from Mexican scientists, which can be sent to the senior author at the Grassland, Soil and Water Research Laboratory, USDA-ARS, P. O. Box 748, Temple, TX 76503. We would be happy to exchange any information or references at our disposal with Mexican scientists. When sufficient information is compiled, it should be analyzed by the scientists of both countries so that a joint decision can be made on whether or not biological control should be attempted for each target weed species.

ECOLOGICAL STUDIES

Woody plants are a natural component of most native rangelands but when overabundant they may greatly limit the amount of forage produced by nonwoody species. The increase of shrubs on western grasslands has taken place on so extensive a scale that it is sometimes viewed with alarm. Thus the occupancy of rangelands by woody plants is perceived as being "... the primary threat to effective use of rangeland in Texas and most of the southwest." (Scifres, 1980). The Soil Conservation Service (Smith and Rechenthin 1964, Hoffman, 1974) identified the "brush problem" as the number one problem of Texas grasslands. The Association of Texas Soil and Water Conservation Districts (1976) listed the problem of brush and weeds on rangeland as second only to taxation in severity. The Great Plains Agricultural Research Committee (1976) in a report entitled "Range Research Needs" recognized a particular need for understanding the ecology of weeds and brush in terms of life histories and population dynamics.

Rangelands are basically natural systems of complex structure and processes. Range management has the general goal of maintaining these systems in productive, predictable (stable) condition in the most efficient manner possible.

Thus, it is important that the components of the system be understood in terms of their relationship to each other and how they will respond to different kinds of management. The interactions among plants, the primary producers in the system, is a first order concern.

The recent observed increase in brush density is popularly ascribed almost wholly to recent abusive management practices, especially to overgrazing (Orev 1956, Buffington and Herbel 1965, Harris 1966). However, some observations suggest that brush increase may be due in part to natural processes that override human influence. The present increase may be a recurrence of a situation that prevailed hundreds or thousands of years ago (Carter 1964, Smeins 1983).

The general hypothesis on which brush research seems to be based either explicity or implicity is that brush (low value forage species) compete with herbs, principally grasses (high value forage species) for the essential resources, water, minerals, and light and that the elimination of low value brush will bring about a corresponding increase in production of the higher value forage species. Results reported in the literature from brush manipulation experiments do not support such a simple hypothesis of interspecific competition (Dahl et al. 1978) but instead suggest that other dynamic relationships among species (some positive, some negative) as well as changes in the physical properties of the environment are important (Tiedemann and Klemmedson 1973, 1977, Halverson and Patten 1975, Brock et al. 1978). The relative magnitude of the various positive and negative effects and their causal relationships need to be established.

Three types of plants that are serious weeds in rangelands of southwestern North America have been selected by one of us (Johnson) for ecological research at the Temple, Texas laboratory. Mesquite (Prosopis glandulosa), juniper (Juniperus ashei and J. pinchotii), and prickly pear cactus (Opuntia spp.) were selected because of their importance and because they represent extremes in adaptive strategies. Mesquite is a decidious shrub with C-3 metabolism, it is a legume and is presumed to fix atmospheric nitrogen (Bailey 1976, Felker and Clark 1980), and it has roots at both moderate and extreme depths. Juniper is an evergreen shrub with conifer-type leaves, also with C-3 metabolism, it has both superficial and deep roots, and it produces strong allelopathic reactions with herbaceous plants. Prickly pear is a succulent with CAM metabolism, it has a very superficial root system, and it is not considered to be a strong competitor with forage plants although it can be a serious management problem (Martin and Tschirley 1969, Laycock 1983). All three types, mesquite, juniper, and prickly pear, are strong invaders of rangelands, particularly of overgrazed ranges.

Little is known about the basic biological processes, potentials, and strategies of the species involved. We are comparing the changes in density between these shrubs and herbaceous species, as influenced by biological and physical factors, from three perspectives: 1) patterns of shrub invasion, 2) the spheres of influence of individual shrubs in the field, and 3) life history and physiological profiles of the shrubs. Also, we are documenting the similarities and differences between native weeds and naturalized exotics.

Changes in herbaceous production are seldom linearly related to the amount of mesquite removed and the pattern of herbage production after mesquite is killed does not correspond to mesquite reinvasion as should be expected if simple competition is all that is involved (Parker and Martin 1952, Dahl et al. 1978). The effect of juniper seems to be more consistent although much of this effect is ascribed to allelopathy in conjunction with competition (Jameson 1966). Our studies to date show that production of herbaceous plants is rapidly depressed by invasion of juniper.

Positive interactions on a local scale are commonly observed among shrubs and their associated plants. Several workers have observed greater herbaceous growth in zones under mesquite trees than in the areas between trees (Halverson and Patten 1975, Tiedeman and Klemmedson 1977); this pattern is associated with improved soil conditions. In the case of mesquite, these positive effects may be caused in part by the N fixing ability of the plant, though this has not yet been established. Increased growth of herbaceous plants has also been observed in association with the nonleguminous shrubs, rubber rabbitbush (Frischknecht 1963) and four-winged saltbush (Johnson et al. 1983).

Research is underway to characterize the nitrogen regimes of mesquite and juniper in relation to environmental factors and nitrogen fixation characteristics. Nodulation has occurred in the greenhouse on mesquite roots growing in soil collected from several areas. Nitrogen in the leaf tissue of mesquite collected in several areas is higher than in leaves of other shrub species growing nearby. Also, ratios of ^{15}N to ^{14}N in some locations indicate that mesquite is fixing atmospheric nitrogen. Nodules have been found on roots of established mesquite trees growing in a variety of conditions in the Temple area.

Ratios of the isotopes of oxygen and hydrogen in water appear to vary with depth in the soil. These ratios allow us to determine from where in the soil profile plants are extracting water. Differences in these relationships may reflect levels of water use efficiency, competition for water, and species tolerance to drought stress. High plant water capacitance appears to prolong periods of gas exchange in prickly pear. Water use efficiency is increased by carbon conservation processes, not only by the recycling of respiratory CO_2 but also by sequestering carbon as oxalates, mostly in the form of calcium salt. Findings on gas-exchange and water-use efficiencies of prickly pear are being extended to test whether water capacitance is related to the ability of mesquite and juniper to compete with herbaceous vegetation in using soil water.

Carbon dioxide response curves for different plant species are being prepared to test the hypothesis that increasing atmospheric CO_2 concentrations favor C-3 woody plants more than herbaceous plants, particularly C-4 grasses. These relationships may partially account for the increase in shrubs over the past several decades and should have important implications in projecting expectations for future vegetation change.

These ecological studies will provide a basis for understanding the interrelationships between invading shrubs and desirable forage plants and how the rangeland ecosystem can be managed for increased efficiency for the multi-use needs of the future.

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Resumen.--Varias especies boscosas y hierbas son malezas en pastizales del suroeste Estados Unidos y norte México. Control biológico por la introducción de organismos (especialmente insectos) de otras areas del mundo (especialmente Argentina) es una metodología posible para controlar especies nativas como Gutierrezia, Baccharis, Flourensia, Larrea, Prosopis, Hymenoxys, Aloysia, Astragalus, Drymaria, Juniperus, Acacia, y especies introducidas de Tamarix y Salsola. De estas especies, objetos para control son seleccionados considerando la cantidad de daño, valores beneficos y ecológicos, y el potencial de éxito. Malezas que presentemente parecen aceptable a los Estadios Unidos y México son Gutierrezia, Baccharis, Flourensia, Hymenoxys y Drymaria; especies adicionalos pueden ser consideradas si los conflictos de interés fueran resueltos. Estudios en USA estan determinando la ecología de la invasión de arbustos en pastizales, particularmente por Prosopis, Juniperus, y Opuntia. Información de México se requieré sobre los valores de daño y beneficios de cada hierba para que decisiónes se puedan hacer en el mejor interes de los dos paises.

Utilizacion y Comercializacion de la Cera de Candelilla[1]

Refugio A. del Campo Pérez[2]

Resúmen.--La cera de candelilla se extrae de la planta del mismo nombre (Euphorbia Antisyphillitica) y sus propiedades hacen que se le emplee en una diversidad de productos que van desde chicles hasta grasas y tintes. La comercialización cubre el mercado nacional y una buena parte del internacional.

INTRODUCCION

La cera de candelilla es un producto que se extrae de la hierba de candelilla y que compite en importancia con el ixtle de lechuguilla y palma Pues estos productos, además de significar una alternativa económica compelementaria para el ingreso de los campesinos de la región, es también un renglón significativo de ingreso de divisas al país, ya que el mercado internacional de la cera representa un 40% de la demanda total, aproximadamente.

La bondad de la candelilla reside en que es un producto que crece y se reproduce sin ningún cuidado, pues es una planta que prolifera en las regiones mas secas del país y, cuanto mas severas son las condiciones climáticas y mas pobre es el suelo, mas y mejor es la cera que segrega (García Cruz, 1939).

Esta hierba se encuentra con profusión en las regiones mas agrestes del Arido Mexicano, en las laderas de cerros y montes, ensuelos calizos y arenosos, bien drenados. Su poca sensibilidad a plagas y enfermedades hace que se le aproveche, muy frecuentemente, como forraje para cabras y conejos, por lo que es común que su explotación se encuentre asociada a actividades de ganadería menor.

La hierba de candelilla con mayor potencial cerífero crece casi exclusivamente en el desierto mexicano y, en este, preferentemente en la parte mas septentrional pues la hierba que se enchuentra hacia el sur, especialmente hacia las costas, tiene un contenido de cera tan reducido que hace incosteable su explotación porque el contenido de resinas supera al de cera y esto la coloca en condiciones de inferioridad respecto a los requerimientos industriales mas usuales. Los principales estados productores de cera son Coahuila, Chihuahua, Durango, Zacatecas y Nuevo León.

Aunque se han hecho intentos de trasplantar la candelilla a países como Haití, Cuba y la República Dominicana los resultados han sido, invariablemente, infructuosos (NAS, 1975).

La reproduccíon de la candelilla, para efectos de reforestación, se lleva a cabo principalmente mediante trasplantes de tallo y raíz ya que la reproducción por semilla no es viable económicamente por el escaso volumen de simiente que produce la planta y la dificultad para recolectarla (García Cruz, 1939).

Su rendimiento de cera es de un 2 a 2.5% del peso de la planta aunque en el laboratorio es posible duplicar el porcentaje usando disolventes (NAS, 1975), lo que quiere decir que con el procedimiento usual solo se extrae el 50%, aproximadamente, del contenido total de cera de la planta y el otro 50% queda entre los residuos y el bagazo.

Alrededor de la cera de candelilla se han formado una serie de instituciones que van desde el propio grupo de campesinos llamados candelilleros hasta la Asociación Nacional de Productores de Cera de Candelilla y los Fideicomisos relacionados con la explotación del producto.

Las actividades de recolección de la hierba y extracción del cerote, como se llama al producto antes de su refinación, son complementarias de las actividades agrícolas tradicionales del campesino candelillero y el ingreso que este percibe por la venta de su producto le permite complementar su percepción y cubrir los gastos de extracción.

USOS

Los usos y aplicaciones actuales de la cera de candelilla son mucho mas variados de los que tuvo en los primeros años de su acceso al mercado, como era la fabricación de mezclas para velas y productos pulidores y abrillantadores para cuero. La diversificación de las manufacturas en general ha planteado nuevas posibilidades para la cera de candelilla y hov es posible encontrar que su ámbito abarca campos de producción tan diversos como la fabricación de cosméticos, la industria alimentaria y el moldeo de precisión en la industria aeronáutica.

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[1] Ponencia presentada en la Reunión Sobre Manejo de Plantas en Zonas Aridas. Saltillo, Coahuila, México. Febrero 18-22, 1985.

[2] Ingeniero Agrónomo. Gerente de Comercialización de los Fideicomisos Relacionados con la Explotación de la Hierba de Candelilla.

Con el afán de ilustrar un poco y sin pretender ser exahustivo, citaré algunos de los usos específicos mas frecuentes y conocidos que tiene la cera en nuestros días ya sea sola o en combinación con otros productos que le agregan nuevas características:

--Como recubrimiento aislante en cables eléctricos y partes en la industria electrónica.

--Como protección de filos y puntas de herramientas para evitar el deterioro durante su transporte y almacenaje.

--Como plastificante en la producción de hules y plásticos para usos múltiples.

--Como componente en la fabricación de barnices, lacas, tintes, grasas, etc. Ejemplo: 'El Oso', 'Amberes', 'Flexo',

--Como agente endurecedor en la fabricación de otras ceras y productos sintéticos.

--Como recubrimiento protector de frutas y en la fabricación de chocolates, chicles y gomas de mascar. Ejemplo: 'Adam's' 'Canel's', 'Omega', 'Totito'.

--Como componente de productos para el acabado fino de cuero y papel.

--Como componente en la fabricación de cintas para máquina de escribir, papel pasante, estenciles. Ejemplo: 'Kores'.

--Como ingrediente en la fabricación de cremas, lápices labiales y otros productos en la industria cosmética. Ejemplo: 'Avon'.

--Como componente de productos para el pulido y abrillantado de madera, pisos y cerámica. Ejemplo: 'Stanhome'.

--Como ingrediente básico en productos para moldeo de precisión en las industrias de relojería, aeronáutica y en la mecánica dental.

Como puede verse, la penetración del producto en el mercado es amplia y actualmente buscamos que sea más profunda pues no se considera que las posibilidades de nuestro producto hayan sido ya agotadas sino que, por el contrario, la constante diversificacion de la producción de todo tipo de artículos en que se requieren ceras, abre constantemente una gama potencial de nuevos mercados que debemos atacar.

COMERCIALIZACION

El mercado de la cera de candelilla puede dividirse practicamente en dos, cada uno de ellos con características y comportamientos propios aunque por lo general coinciden en los usos y aplicaciones del producto.

El mercado nacional es mas estable y está menos expuesto a fluctuaciones debido a la protección que el estado brinda a los productores de cera y que consiste, entre otras cosas, en condicionar la importacion de sustitutos industriales de la cera de candelilla, condicionandola al consumo de determinados volumenes de esta, dependiendo de la rama o giro industrial de los fabricantes. A manera de ejemplo podemos citar a los productores de ceras, grasas y tintes que deben consumir 4 kg de cera de candelilla por cada kilogramo de carnauba que importen, o los fabricantes de papel carbón, cintas para máquina y esténciles, que deben consumir un kilogramo de cera de candelilla por cada 2.5 kilogramos de carnauba.

Si a lo anterior se auna la existencia de un precio oficial del producto se verá que el mercado nacional está, en mucho, controlado sin embargo, la situación dista mucho de ser ideal pues existen algunas áreas del mercado que deben superarse. Quizá la mas frecuentemente mencionada es la de que la cera de candelilla, en su forma actual, por ser un producto de origen natural, tiene algunas fluctuaciones en sus características fisicoquímicas que, aunque pequeñas, representan una desventaja frente a las ceras sintéticas y parafinas, de origen mineral, en los casos en que se requiere su participación en formulas de mucha precisión, como es la fabricación de alimentos y cosméticos. Afortunadamente ese segmento del mercado en el que no hemos podido penetrar completamente solo representa un 23% aproximadamente, de la demanda total (ver figura página siguiente).

El mercado internacional presenta mayores fluctuaciones que actualmente se está buscando corregir para llegar mas directamente a los consumidores de cera pues consideramos que la demanda de nuestro producto es constante y va en aumento y que sus fluctuaciones son inducidas artificialmente por los especuladores para obtener mayores beneficios. La base de esta consideración es el hecho de que se cuenta con un 'stock' suficiente del producto para no quedar expuestos a la oscilación en los volúmenes de materia prima, ademas de que el precio al exterior se mantiene constante desde hace tiembo.

Aunque debemos reconocer que nuestro sistema de comercialización aún debe superarse hay que recordar que la comercialización por parte del Fideicomiso de la Hierba de Candelilla se comenzó con 150 toneladas en los inicios de los años sesentas y con una estructura de producción y refinación rudimentaria y que en la actualidad las ventas superan las 1,200 toneladas anuales ademas de que se tiene una estructura de recopilación, refinación y distribución mucho mas estable.

Es necesario insistir en que las ceras naturales, lejos de estar siendo desplazadas por las sintéticas y las de origen mineral -grasas y parafinas- son un complemento indispensable para su fabricación pues a partir de las ceras de origen vegetal se obtienen los componentes para sintetizar y mejorar los productos cada vez mas

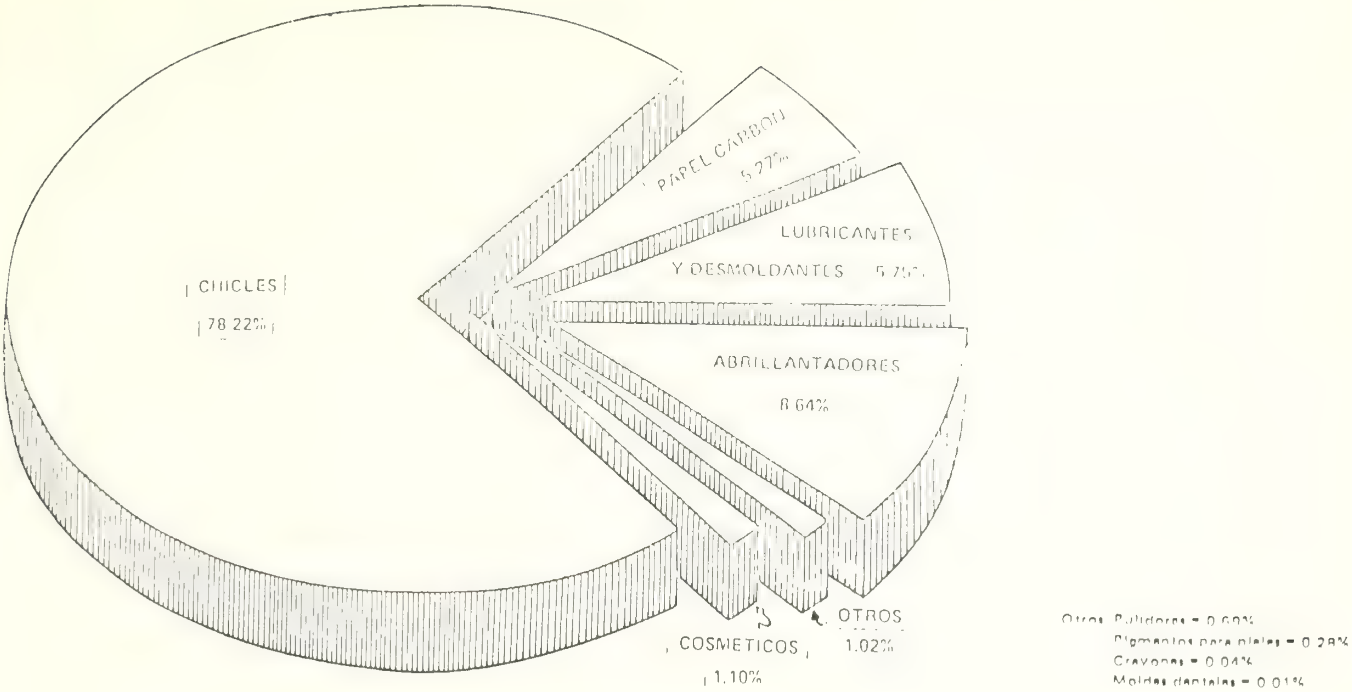

Figura Sectores de consumo de cera de candelilla en el mercado nacional.

diversos y complejos que requiere la industria moderna.

La solución a buena parte de los planteamientos que se han hecho antes respecto a una mas intensiva penetración de la cera de candelilla en el mercado estriba, fundamentalmente, en la diversificación del producto para satisfacer y captar a consumidores con requerimientos especiales y en llevar, mas directamente, el producto a países y regiones donde aún no se haya penetrado, pues aunque la cera se distribuye en la mayoría de los países de Europa Occidental -España, Francia, Italia, Alemania, Bélgica- de los Estados Unidos y Canada y de América Latina -Argentina, El Salvador, Guatemala- y aún en algunos paises orientales como Japón y Turquía, consideramos que aún hay mucho mercado por ganar y actualmente se afinan relaciones comerciales para la colocación de nuestro producto en países como la India y otros del Medio Oriente así como con Grecia y otros países de Europa Oriental.

Lo anterior va, necesariamente, de la mano de los correspondientes estudios de ampliación y reestructuración de sistemas y canales de comercialización ya que la perspectiva de un mercado en expansión, de la magnitud que se pretende, presenta un horizonte quizá demasiado amplio.

INVESTIGACION

La investigacion en torno a la cera de candelilla, que se considera una necesidad impostergable, podría agruparse en dos grandes apartados con puntos de vista diametralmente opuestos en apariencia, pero que en realidad son complementarios por una parte la investigación que se ha hecho y se hace actualmente con un enfoque científico, de laboratorio, y por la otra la investigación que se enfoca mas hacia los aspectos técnicos y operativos que si se ha hecho en algunos casos, no ha resuelto todos los problemas que se tienen.

La investigación de gabinete y laboratorio busca la determinación de características y propiedades de la cera y de procedimientos alternativos de extracción para reducir el desperdicio durante el proceso y se buscan, también, nuevas aplicaciones del producto adicionándole tal o cual componente para darle nuevas propiedades pero hasta hace poco no era mucho lo que se había hecho para abordar sistemáticamente la diversificación del producto y la consolidación y ampliación del mercado.

La prioridad, desde nuestro punto de vista y teniendo en mente los intereses de los productores candelilleros, es el estudio del mercado, que es algo en lo que ya se está trabajando, al mismo tiempo que se busca aumentar la producción, pues este otro aspecto de las investigaciones nos interesa, de manera muy particular, cuando de refiere a procedimientos que permitan aumentar la eficiencia de los procesos actuales abatiendo costos, aumentando rendimientos por kilogramo de hierba y suavizando las condiciones de recopilación y extracción para el compesino, pues todo esto nos permitiría sostener nuestros precios por mas tiempo en el mercado y nos daría mucha mas competitividad frente a otros productos.

Nuestra idea del proceso de comercialización es que este parte del momento mismo de la recolección de la hierba, pasando por el proceso de extracción del cerote y su refinación y, eventualmente, la producción de productos diversos, su presentación y empaque hasta llegar al consumidor satisfecho de nuestro producto. La cadena es compleja y si no se tiene cuidado, se corre el riesgo de tropezar, por eso estimamos indispensable un conocimiento lo mas minucioso y detallado posible del mercado para establecer un flujo constante de nosotros hasta nuestros consumidores. En la medida en que logremos un flujo expedito podremos aumentar nuestra penetración en el mercado y pasar de la estructura de producción actual a una que sea mucho mas eficiente, para lo cual se requerirían estudios e investigaciones adicionales.

Con la interción de ser breves podríamos resumir la investigación que se requiere sobre la hierba y la cera de candelilla a partir de los siguientes enfoques.

Agronómico

Lo mas importante de este enfoque sería continuar con los estudios de adaptación y domesticación del cultivo pues solo con ello se lograría aprovechar al máximo el potencial integral de la planta. A esto deberían agregarse estudios de mejoramiento genético para aumentar la secreción de cera y disminuir el de algunos componentes no deseados creando variedades mas adecuadas a las necesidades del mercado. El mejoramiento de las técnicas de cultivo y de manejo en general. La asociación de cultivos es un aspecto importante con miras a la conservación no solo de este recurso natural sino de otros con los que se presenta en su habitat natural. Los estudios para la reforestación y rescate de zonas devastadas y otros tendientes a la mas recional explotación de la hierba.

Técnico-Industrial

A partir de este enfoque la investigación se centraría en el proceso de extracción, refinación y diversificación de la cera de candelilla y el aprovechamiento óptimo de los subproductos y residuos de la producción de cera en sus diversas fases, tanto en el campo como en la planta.

Económico

Aquí cabrian las investigaciones referentes a los aspectos de mercado, incluyendo transporte y almacenaje así como la asociación de las actividades de recolección y extracción de cerote con algunas otras actividades productivas que conforman el sistema integral de producción campesino con el propósito de aumentar la eficiencia y productividad del trabajo del candelillero así como la de los demas factores que incurren en el proceso desde las etapas iniciales hasta las finales.

Sociales

Finalmente, aunque no en último lugar, es necesario realizar investigaciones continuas para el mejoramiento de las condiciones generales y la calidad de vida de los asentamientos humanos donde se produce la candelilla, con la finalidad de planificar apropiadamente las obras e inversiones de beneficio social que son el propósito de una de las instituciones candelilleras de que hablabamos al principil; el Fideicomiso para la Hierba de candelilla.

El panorama general que, por necesidades de sistema y claridad, se presenta aquí separado partiendo de varios enfoques, en la práctica deberá conformar una visión completa della región candelillera con un eslabonamiento y una interdependencia estrecha entre los estudios que se realicen para que sean unos el complemento y fundamento de los otros y se optimicen tanto los resultados que se obtengan, como los recursos que a ellos se apliquen.

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Summary.--The Candelilla wax is extracted from the plant of the same name (Euphorbia antisyphillitica) and because of its properties it is used in a great variety of products, from chewing gums to oils and dyes. The commercialization of this product covers the national market, as well as great part of the international market.

Candelilla: la Necesidad de un Cambio

Obed Chávez Pruneda[2]

Resumen.--La siguiente ponencia toma los resultados de un estudio desarrollado en 1979 y mediante el cual se lograron identificar diferentes argumentos, la mayoría de ellos aun válidos, que justifican un cambio en todas las etapas del proceso de aprovechamiento de la cera de candelilla.

ANTES DE 1979

Previo a 1979, se habían venido desarrollando una gran cantidad de estudios que sobre diferentes aspectos y en diferentes partes del mundo tuvieron como parte central a la candelilla (cuadro 1).

El desfasamiento en el tiempo y en el espacio de todos estos estudios, les hizo ser aislados, y por lo mismo en la gran mayoría de ellos las aportaciones importantes que sus resultados pudieron hacer al mejoramiento del sistema comercial en operación fueron muy pocas. Por otro lado, el sistema comercial de la candelilla durante este tiempo se mantuvo ajeno a un buen número de tales resultados. Además, muchos aspectos que requirieron y aun requieren de consideración, no hubo quien los atendiera.

De una manera u otra, faltó una visión de todo el sistema comercial, con la intención de que conociéndolo en su totalidad, pudieran plantearse opciones que permitieran mejorar sensiblemente su funcionamiento.

1979

Así, con algunos antecedentes en torno a la candelilla, y con la preocupación tanto de la ineficiencia del proceso de extracción de la cera como de la posible erradicación del recurso, el CIQA con el apoyo de BANRURAL (ahora FONCAN) y CONAZA, se echa a cuestas la tarea de evaluar las posibilidades de innovar el proceso global de aprovechamiento de la candelilla.

Para tal propósito, se integra un equipo de investigadores de diferentes especialidades y pertenecientes a las tres instituciones mencionadas.

Mediante el estudio se integró la información ya existente en un formato que permitiera la comparación entre los dos sistemas de aprovechamiento de la candelilla: Actual (H_2SO_4) y Propuesto (Solvente). De esto se derivó la estructuración de un archivo de artículos, patentes, tesis y libros que actualmente se encuentra en la biblioteca del CIQA. La información faltante, se generó con trabajo de campo.

Algunos de los aspectos relevantes que se detectaron en el desarrollo del estudio son los siguientes:

"El aprovechamiento comercial de la candelilla se remonta a principios de siglo; la extracción de la cera con el método que actualmente se usa (ácido sulfúrico H_2SO_4) data de 1912."

La actividad candelillera involucra alrededor de 3500 productores, teniéndose un registro al regimen del IMSS de 20,000 personas.

El sistema de producción actual de la cera de candelilla, requiere en mano de obra, 2087 hr-h/ton de cera producida. Esto significa que, considerando semanas de 40 horas, se requiere del trabajo de una persona durante 1 año para producir una tonelada de cera.

Por otro lado, el tiempo que se dedica a las diferentes labores del quehacer candelillero, se distribuye según se muestra en el cuadro 2.

Podrá observarse que una buena parte (33%), es tiempo improductivo que además mantiene dispersos a los candelilleros y cada vez más alejados de sus lugares de origen.

Pudimos observar, que la producción presenta una distribución muy hetero génea, pues si por un lado hay quienes producen de 2-3 veces su cuota (27% de los ejidos), hay quienes ni siquiera complen con el 20% de la misma (10% de los ejidos). Como resultado de esto, se observó que solo el 15% de los ejidos (34) son responsables del 42% de la producción.

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[1] Ponencia presentada en la Reunión Sobre Manejo de Plantas en Zonas Aridas. Saltillo, Coahuila, México. Febrero 18-22, 1985.

[2] Ingeniero Químico, Jefe del Area de Estudios y Proyectos Especiales, - CIQA, Saltillo, Coah.

Cuadro 1. Lista de los estudios más importantes que sobre candelilla se realizaron hasta antes de 1979.

Tipo de estudio	Nivel	Año	Institución que realizó el estudio	País
Análisis de la cera	3	1907	Instituto Médico Nacional	México
Análisis de la cera	3	1910	Texas Agricultural Experiment Station	U S A
Análisis de la cera	3	1925	Laboratoire Municipal de París	Francia
Blanqueo y refinación de la cera	3 4	1936	Institut fur Chemische Technologie II der Deutschen Technischen Hochschule	Alemania
Recopilación de información	1 5	1939		México
Propagación de la Candelilla	1	1942	Escuela Nacional de Agricultura	México
Estudio sobre la actividad proteolítica del látex de la Candelilla	3	1942	Escuela Nacional de Ciencias Biológicas, I.P.N.	México
Estudio botánico de la Candelilla	1	1944	Instituto de Biología, U N A M	México
Metodo para determinar el numero de saponificación de ceras	3	1949		Alemania
Método para determinar el número de saponificación de ceras	3	1949	Laboratoire des Corps Grass du C.N.R.S.	Francia
Análisis de la cera	3	1949	University of Wisconsin	U S A
Efecto de la composición sobre la gravedad específica en mezclas de ceras	5	1950		U S A
Uso de la cera en compuestos para pulir	5	1952		U S A
Estudio de la extracción y refinación de la cera	4	1952	Instituto Mexicano de Investigaciones Tecnológicas	México
Estudio de la extracción de la cera y obtención de pulpa celulósica de Candelilla	4 5	1953	Instituto Mexicano de Investigaciones Tecnológicas	México
Estudio de la extracción y refinación de la cera y obtención de pulpa de la Candelilla	4 5	1953	Instituto Mexicano de Investigaciones Tecnológicas	México
Estudios de la refinación de la cera	4	1953	Southwest Research Institute	U S A
Recopilación de información	1 5	1953	Engineering Experiment Station of Georgia, Institute of Technology	U S A
Recopilación de información (tesis)	1 5	1954	Escuela Superior de Agricultura Antonio Narro	México
Recopilación de información	1 5	1954		U S A
Análisis de suelos candelilleros y contenido de cera en la Candelilla (tesis)	1	1954	Escuela Superior de Agricultura Antonio Narro	México
Recopilación de información	1 5	1955		U S A
Estudios del indice de refraccion de mezclas de ceras	3 5	1955	Ursuline College Louiseville, Kentucky	U S A
Determinación de hidrocarburos en cold cream	5	1956	Food and Drug Administration	U S A
Estudios de las propiedades impermeabilizantes de la cera	5	1956		Francia
Análisis de la cera	3	1957		Alemania
Estudio histoquímico y determinaciones en el extracto cereo de la Candelilla (tesis)	1	1957	Escuela Nacional de Ciencias Químicas, U N A M	México
Contribución al estudio de la Candelilla	1 5	1958	Escuela Superior de Agricultura Antonio Narro	México
Recopilación de información	1 5	1958	Escuela Nacional de Agricultura	México
Recopilación de informacion	1-5	1964	Instituto Mexicano de Recursos Renovables, A C	México
Propiedades físicas y químicas de ceras vegetales	3	1969		U S A
Identificación de la cera por cromatografía en capa delgada	3	1971	Farbewerke Hoechst AG Werk Gersthofen	Alemania
Análisis sistemático de la cera	3	1972	Shiseodo Laboratory-Kamiya, Kita Ku	Japón
Recopilación de información (tesis)	1-5	1972	Escuela Nacional de Agricultura	México
Análisis de la cera	3	1973	Instituto Mexicano de Investigaciones Tecnológicas, A.C.	México
Análisis de la cera	3	1973	Prairie Regional Laboratory	Canadá
Uso de la cera en el recubrimiento de frutas	5	1974	Laboratorios Nacionales de Fomento Industrial	México
Aplicación de la cera al recubrimiento de frutas	5	1974	Comisión Nacional de Fruticultura y Facultad de Química, U.N.A.M.	México
Análisis de la cera	3	1974	The University of Michigan	U.S A.
Análisis de la cera	3	1974	Prairie Regional Laboratory	Canadá
Recopilación de información	3-5	1975		U S A
Análisis de la cera	3	1975	Prairie Regional Laboratory	Canadá
Análisis de la cera por GPC y VPO	3	1975	Centro de Investigación en Química Aplicada	México
Cloración de la cera	5	1975	Centro de Investigación en Química Aplicada	México
Evaluación de la cera clorada como plastificante en PVC	5	1975	Centro de Investigación en Química Aplicada	México
Análisis de la cera	3	1976	Fire Investigación Sec. NIPS	Japón
Análisis de la cera	3	1976	Institut fur Organische Chemie and Biochemie, Tschechoslowakische Akdemie der Wissenchaften	Checoslovaquia
Diversificación de su uso	3-5	1977		México
Análisis de la cera	3	1977	Laboratories Wolf	Francia
Evaluación cualitativa y utilización de residuos de Candelilla en la alimentación de rumiantes (tesis)	5	1977	Escuela Nacional de Agricultura	México
Estudio socioeconómico de los candelilleros del area periférica de la comarca lagunera	S E	1977	Centro de Investigaciones Superiores del INAH	México
Mejoramiento de las propiedades térmicas de la cera	5	1977	Centro de Investigación en Química Aplicada	México
Extracción de la cera con solventes	4	1978	Centro de Investigación en Química Aplicada	México
Análisis de carbohidratos en el bagazo	3	1978	Centro de Investigación en Química Aplicada	México
Estudio descriptivo en cuatro ejidos candelilleros	1 S E	1978	Universidad Autónoma Agraria Antonio Narro	México
Recopilación de información	1 S.E.	1979	Universidad Autónoma Agraria Antonio Narro	México

Claves de los niveles

1 La planta 2 Abastecimiento 3 Propiedades y composicion quimica 4 Transformacion
5 Distribución usos subproductos S E Estudio socioeconomico

Cuadro 2. Composición del tiempo consumido en la obtención de 1 ton de cera.

Actividad	%
Traslado y transporte de la hierba	33
Recolección y empaque del arbusto	36
Extracción del cerote	30
Refinación	1

Un aspecto que no ha recibido la atención que merece, es lo relacionado al inventario del recurso, pues el único estudio que se conoce que tuvo este objetivo se desarrolló en 1965 y la única información que generó en torno a la candelilla fue:

Area ocupada = 85,580 km^2

Area explotada = 47,025 km^2

En cuanto al mercado de la cera pudimos identificar sus usos, productos competitivos, países consumidores, propiedades y establecer estadísticas en relación con su demanda, producción, exportaciones y precios.

Con relación a lo ambiental, pudimos observar que por cada tonelada de cera que se produce actualmente, se descartan al ambiente 0.5 ton de ácido sulfúrico. Además no hay ninguna acción tendiente a preservar el recurso, dadas las actuales prácticas de recolección del arbusto y a la ausencia total de algún sistema que asegure su recuperación.

Del análisis efectuado en el estudio, se derivaron resultados tales como los siguientes:

Con base a los municipios reportados como candelilleros a la fecha del estudio, pudimos estimar la superficie de la región candelillera, misma que resultó ser de 172,064 km^2; la división de esta región, atendiendo al criterio de contribución a la producción, dio como resultado: 2 zonas de 1000 ton/año cada una, 1 de 500 ton/año y 1 de 200 ton/año.

Los resultados obtenidos en el análisis financiero de las diferentes opciones propuestas se muestran en el cuadro 3.

Cabe hacer énfasis en que un análisis del los componentes del costo de producción en el sistema con solventes intermitente, revela que el 46% se debe al costo de la candelilla, por lo que resulta obvia la necesidad de minimizar en lo posible este concepto.

Cuadro 3. Resumen de los resultados de la evaluación financiera de las opciones propuestas.

Concepto	Sistema		
	Actual (H_2SO_4)	Propuestos Intermitente	Propuestos Continuo
Costo de producción, $/kg	37	26 (70%)*	23 (62%)*
Precio de venta, $/kg	40	35	35
Inversiones, millones de pesos	-	34	39
Punto de equilibrio, %	-	50	37
Tasa interna de retorno, %	-	15	20
Recuperación de inversión, años	-	5.5	4.5

* Porcentaje con respecto a costo del proceso actual

Una comparación entre las necesidades de los dos sistemas (actual y propuesto) permite destacar los siguientes puntos:

*La superficie requerida en abastecimiento para el sistema propuesto es aproximadamente 1/3 de la que se dedica en el sistema actual

*Los requerimientos de energía en la transformación del sistema propuesto son del orden de 1/5 de los del actual

*La eficiencia de extracción de la cera en el sistema propuesto es prácticamente el doble de la del actual.

*En términos de mano de obra, el proceso propuesto requiere en total, solo el 55% del tiempo del actual. En la fase de abastecimiento el sistema propuesto solo requiere un 66% de las necesidades del actual, mientras que en transformación el porciento es de 30% (cuadro 4)

*En lo que se refiere a calidad, aparentemente el tratamien to con ácido sulfúrico es tan severo, que se cree que modifica la estructura química original de la cera, en detrimento de sus propiedades finales.

Finalmente, el análisis realizado se integró en la presentación de unproyecto, en el que el propósito fundamental era substituír gradualmente el sistema actual de aprovechamiento de la candelilla por otro más racional y eficiente; se elaboraron el calendario de actividades y los presupuestos correspondientes.

Los aspectos más importantes que en este proyecto se planteaba cubrir son:

Abastecimiento
- .Inventario
- .Estudio ecológico
- .Reforestación
- .Cultivo

Transformación
- .Estudios piloto del proceso de extracción con solventes
- .Opciones de utilización del bagazo
- .Ingeniería básica
- .Estudio de preinversión
- .Ingeniería de detalle
- .Construcción de una planta de 1000 ton/año
- .Construcción de 5 plantas intermitentes (1000 ton/año cada una)
- .Proceso continuo

Distribución
- .Estudio de mercado

Estudios especiales
- .Estudio socioeconómico
- .Transferencia tecnológica

DESPUES DE 1979

El planteamiento del proyecto no logró la aceptación y el apoyo que se esperaba, particularmente en las instituciones adecuadas para tal fin. Sin embargo, con los pocos recursos que se pudo contar, el CIQA apoyado por CONAZA logró sacar algunos de los aspectos planteados en el proyecto:

Cuadro 4. Requerimientos de mano de obra, expresados en - hr-h/ton de cera.

Actividad	Proceso actual H_2SO_4		Proceso propuesto Solvente	
Abastecimiento		1447		952 (66%)#
. Recolección y empacado	762		300 (39%)#	
. Transporte	685		373 (54%)#	
. Reforestación	-		244	
. Desmonte	-		35	
Transformación		640		192 (30%)#
. Extracción	624		192	
. Refinación	16		-	
Total		2087		1144 (55%)#

# Porcentaje de requerimientos con respecto a los del proceso actual

* En lo que se refiere a calidad, aparentemente el tratamiento con ácido sulfúrico es tan severo, que se cree que modifica la estructura química original de la cera, en detrimento de sus propiedades finales"

- .Estudios piloto del proceso de extracción con solventes
- .Sondeo de posibles opciones de utilización del bagazo
- .Elaboración de la ingeniería básica del proceso de extracción con solventes
- .Estudio de localización para una planta de 1600/año
- .Estudio de mercado nacional para la cera de candelilla

El proyecto como tal, continúa débil en muchos aspectos: En cuanto al recurso poco sabemos; del mercado, lo mismo (sobre todo con lo cambiante que es) y en cuanto a la idea de integrar todo resultado dentro de un marco con gruente de objetivo común (proyecto), estamos como al principio.

Si en algo podemos decir que hemos avanzado, es en el conocimiento del proceso de obtención de cera usando solventes, pero aun ahí, todavía tenemos carencias.

Es evidente pues, la necesidad de un cambio; es posible llevarlo a cabo, pero para empezar, este cambio debe llevar como uno de sus componentes y quizá el más importante, el cambio en actitudes.

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Summary.--This work has taken the results of a study developed in 1979, in which it was possible to make different statements, most of them currently strong, that justify a change in all stages of the Candelilla wax exploitation process.

Yerba del Manso: An Evaluation[1]

Margaret Caffey-Moquin[2]

Abstract.--*Anemopsis californica* (Saururaceae) is a rhizomatous plant native to moist, low-elevation habitats within the arid regions of the southwestern United States and northern Mexico. Throughout its geographic range, the plant holds an important place in traditional folk medicine, especially as a vulnerary. It has also been reported as a stomachic, a cardiovascular tonic, a diuretic, and cough suppressant. Published ethnobotanical and phytochemical observations on *Anemopsis* are combined with preliminary results of new investigations for an evaluation of the plant's potential as a source of useful medicines.

INTRODUCTION

"Yerba del manso" is a colloquial name used in New Mexico for *Anemopsis californica* (Nutt.) Hook. and Arn. (Fam. Saururaceae). In other parts of the southwestern United States, particularly California, the similar name "yerba mansa" appears to prevail (Curtin 1947). In Mexico, the plant may be known as "bavisa" (Ford 1975). Most Indian languages that have developed within the plant's geographic range contain one or more appellations that often relate to specific medicinal applications. Because the genus *Anemopsis* is monospecific, the generic epithet will be used below.

Two morphologically distinguishable varieties of *A. californica* have been described by Kelso (1932) and were considered by him to occupy more or less disparate parts of the overall geographic range of the species (see fig. 1). An unexpected occurrence of var. *californica* within the area typically occupied by var. *glabra* (Caffey-Moquin 1984) may provide supporting evidence for the hypothesis that the present-day distribution of *Anemopsis* has resulted from anthropochory. The fact that *Anemopsis* is restricted to hydric habitats--more or less isolated oases surrounded by desert--may serve to further corroborate this view. It may now be apparent to the reader that *Anemopsis* is hardly a xerophyte; it is, however, limited to the desert biome (*sensu latu*) of North America, and its continued ethnomedicinal importance is evident in the ubiquity of its folk-usage among the human inhabitants of those arid lands.

Nearly all of the early ethnobiologists working in the Greater Southwest (northwestern Mexico and the southwestern United States) included *Anemopsis* in their lists of plants useful to the peoples with whom they had made contact. Dried *Anemopsis* rhizomes are almost always featured among medicinal herbs offered for sale at open-air markets in New Mexico. They are also standard at regional fairs such as that of San Francisco at Magdalena de Kino, Sonora (Nabhan 1982). There are several major categories of disease that traditionally have been treated with *Anemopsis*. In the ethnobotanical literature, the most consistent application of *Anemopsis* appears to be as a vulnerary poultice, whether the leaves or rhizomes are employed.

Somewhat less prevalent in the literature, yet stressed in personal interviews conducted in New Mexico, is the plant's reputed value as a stomachic for both ulcers and dysentery. In this context, a decoction is typically prepared from the roots and rhizomes and drunk at frequent intervals.

Anemopsis rhizomes may also be employed in "blood purification" (Moore 1977), an ambiguous term which may imply a cardiotonic effect. Gogel (personal communication) has related that a routine radioimmunoassay of the blood of a cardiac patient who frequently ingested *Anemopsis* tea while simultaneously receiving prescribed digoxin therapy revealed unexpectedly elevated blood levels of diogoxin-type antigens. This suggests that *Anemopsis* may contain substances,

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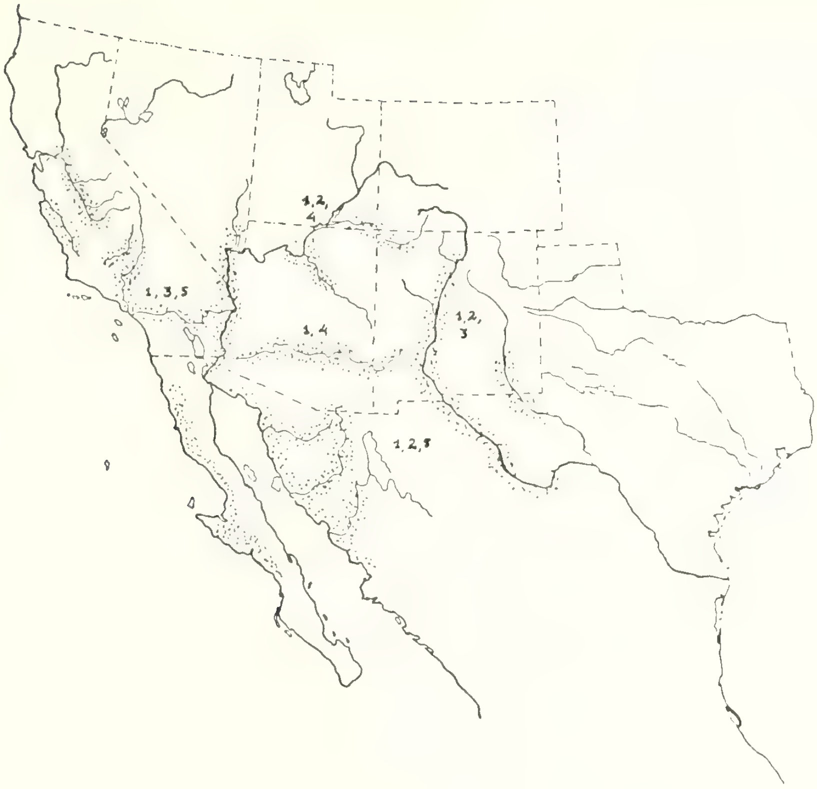

Figure 1.--Potential geographic distribution of Anemopsis californica. Numerals encode localities of reported ethnomedicinal uses as follows: (1) vulnerary; (2) stomachic; (3) cardiovascular tonic; (4) diuretic; (5) cough suppressant.

presumably cardioactive, whose radioimmunoassay behavior resembles that of digoxin.

Anemopsis was reported as the major ingredient of at least one diuretic prescription of Eastern Navajo healers interviewed by Wyman and Harris (1947). Its internal use in the treatment of venereal disease (Train et al. 1957, Hrdlička 1908) may relate to diuresis. In the western part of its range, i.e., in California, Anemopsis has been used as a cough suppressant (Childs and Cole 1965, Zigmond 1981).

Horton and Paul (1957), Sanvordeker and Chaubal (1969), and Tutupalli et al. (1973) reported, respectively, the isolation of three phenylpropanoids, methyl eugenol, esdragol, and elemicin from essential oil of Anemopsis. Methyl eugenol, reported as the major constituent of Anemopsis oil by Acharya and Chaubal (1968), is thought to be mutagenic (Ames 1983). On the other hand, it has been tested for antitumor activity (Childs and Cole 1965), with negative results when strict activity criteria were applied. Pronounced antispasmodic activity was exhibited by methyl eugenol in another assay performed by Childs and Cole (1965); however, the authors found a widely available commercial preparation to be far stronger.

Tutupalli and Chaubal (1971), from their analysis of a light-petroleum extract of Anemopsis, reported the third isolation of (+)-asarinin from a plant source. The authors did not speculate on the possible medicinal applications of this compound; however, its isomer (-)-asarinin, has apparently been used as an antitubercular agent (Merck 1968). Piperitone and thymol composed varying proportions of Anemopsis oil, according to whether fresh or dried plant materials were extracted. Thymol, the second most abundant constituent (Tutupalli et al. 1973) of the "commercial drug" (sic) [probably dried rhizones] has antifungal properties according to Merck (1968).

SOME PRELIMINARY INVESTIGATIONS

Bioassay

A decoction of Anemopsis was obtained by boiling 9.0 g of intact dried rhizome in 250 ml H_2O for 15 minutes. This procedure simulated the usual home preparation method, except that the infusion was triple the normal strength. The extract was passed through a 0.45 µm filter into a sterile flask to avoid the introduction of any undesired microorganisms to the experiment.

Five enteric pathogens were chosen for the assay: *Vibrio cholera*, the cholera pathogen; *Salmonella typhimurium* and *Shigella flexnerii*, two commonly encountered causes of food poisoning; and *Enterobacter aerogenes* and *Escherichia coli*, typical components of normal intestinal microflora that may become pathogenic under unusual conditions. *Vibrio* was cultured in BHI broth and BHI agar (Difco); all others were cultured in nutrient broth and nutrient agar.

Experimental culture tubes contained a mixture of filtered extract and the nutrient medium appropriate to the inoculum. Each organism was inoculated into a five-fold dilution series of extract in culture medium. Normal growth of organisms, as evidenced by visible turbidity, was ascertained by culturing an inoculated tube of pure medium for each organism. Two tubes of pure extract, uninoculated, were incubated along with the others to make certain that the extract itself was sterile.

A parallel test using growth plates was carried out at the same time. Extract was applied dropwise to saturate 0.45 μm filter discs (Millipore) of 1 cm diameter kept in an enclosed sterile dish. Plates containing nutrient medium were inoculated using the streak-plate technique to result in four dilutions of inoculum on each plate. Two replicates were inoculated with each organism. Saturated filter discs were placed onto the junction of the second and third dilution sections of each plate.

The experimental control for each organism in the growth-plate experiment consisted of one plate inoculated with that organism in the manner described above, but with a dry filter disc containing no extract. All plates and tubes were incubated at 37°C for 48 hours before final observation.

No definite inhibition of growth was observed for any of the organisms exposed to *Anemopsis* extract, whether in tube or plate culture. A slight depression of growth, however, was observed at the highest concentration of extract for tube cultures of *Shigella* and *Salmonella*. Because the uninoculated extract controls exhibited no growth, the experimental conditions can be presumed to have been aseptic. Moreover, the organisms in pure culture displayed normal growth, indicating that appropriate growth conditions were maintained.

Cardiac Glycoside Screen

A typical cardiac glycoside consists of an aglycone and its attached deoxy sugar(s). The aglycone comprises a steroidal nucleus and an unsaturated lactone ring. The latter is apparently the principal molecular locus of cardioactivity involving Na^+-K^+ exchange (Tyler et al. 1981); however, the steroidal nucleus is an intrinsic part of the aglycone and may play a specific role of its own. Cardioactive aglycones may be either cardenolides or bufadienolides; i.e., they may possess either a butenolide or a pentadienolide lactone ring, respectively (Sim 1967). Because of its pharmocological importance and ease of detection, the lactone ring is often the first functional group to be screened.

The Kedde test is designed to detect the presence of butenolides, or 4-C unsaturated lactone rings (Sim 1967). The Bush and Taylor modified reagent (Fong et al. n.d.) is prepared by adding 50 ml 5.7% (w/v) KOH to 1.00 g 3-,5-dinitrobenzoic acid dissolved in 50 ml MeOH and is suitable for spraying. An alcohol solution of pure cardenolide is typically colorless and will rapidly change to violet upon treatment. Crude plant extracts containing butenolides may be expected to evince other color changes.

In order to maximize potential retrieval of cardiac glycosides from *Anemopsis*, a large-volume extract was made. Five hundred grams of dried rhizomes and roots were ground in a Wiley mill fitted with a 1 mm sieve. The powder was extracted with 1000 ml methanol (99%) in a shaker bath (80 oscillations/min) for 1 hour at 37°C. Addition of 500 ml methanol facilitated the recovery of the supernatant, and the remaining slurry was decanted in portions into a mortar. Each portion was crushed to a paste, then filtered. The resulting filtrates were recombined with the original supernatant to yield a total of 800 ml of dark brown extract.

Petroleum ether (120 ml) was combined with the extract in a separatory funnel. The more nonpolar of the two resulting emulsion layers (fraction I) was redissolved in 300 ml petroleum ether, evaporated *in vacuo* to a syrup (150 ml) and repetitively extracted with water. The residues of each aqueous extraction were named fractions II - IV in order of decreasing polarity.

Crude methanol extracts were obtained by adding 10 ml solvent to 0.5 g ground plant tissue (*Anemopsis* rhizome or *Digitalis* leaf). After thorough crushing in a hand-held glass homogenizer, each slurry was filtered. The cardenolide standards were two constitutents of *Digitalis* leaf digitoxin and lanatoside A kindly supplied by Dr. Bliss, College of Pharmacy, University of New Mexico. Approximately 100 mg of each cardenolide was dissolved in separate aliquots (2 ml) of methanol.

Four fractions of the large-volume *Anemopsis* extract were assayed simultaneously with the preparations just described (see table 1). Pure methanol was used as a control. All samples were applied to Whatman #3 paper with capillary tubes. Each test spot consisted of ten sample aliquots applied serially to the same point, with air-drying between each pair of applications. Kedde reagent was sprayed over the sample array until the paper was thoroughly wetted.

Treatment produced instantly observable changes in the colors of both pure cardenolides and of the crude methanol extracts of both

Table 1.--Kedde Test Results

Source		Color of Sample	
Species	Sample	Before treatment	After treatment
(none)	MeOH	none	no change
Digitalis sp.	crude MeOH extract	grass green	olive green†
"	digitoxin in MeOH	none	iris purple†
"	lanatoside A in MeOH	none	pale iris†
Anemopsis californica	crude MeOH extract	transparent straw	medium brown†
"	fraction I (MeOH/p. eth.)	light brown	no change
"	fraction II (MeOH/p. eth.)	brown	no change
"	fraction III (MeOH/p. eth.)	rich brown	no change
"	fraction IV (MeOH/p. eth.)	pale tan	†

† Pronounced dark ring surrounded spot after treatment.

Digitalis and *Anemopsis*. Pure methanol displayed no color change. Fractions I - III of the large-volume extract did not change; in contrast, a ring formed around fraction IV.

DISCUSSION

As noted above, the bioassay demonstrated no inhibition of the organisms cultured with *Anemopsis* extract. A slight depression of growth was observed at the highest extract concentration extract in tube cultures of *Shiqella* and *Salmonella*. The attainment of that concentration, however, required such an adjustment in the amount of available nutrient medium that the observed growth depression may be attributable to a paucity of nutrients rather than to the concentration of extract *per se*. It can be concluded that, even at triple the typical concentration of *Anemopsis* decoction, *in vitro* inhibition of the enteric pathogens tested was not confirmed.

While a myriad of modifying influences may accompany the *Anemopsis*-pathogen interaction *in vivo*, and may even tip the balance in favor of inhibition, the results of this experiment cannot be said to support the idea that the usefulness of *Anemopsis* in the treatment of dysenteries is strongly related to direct antibiotic activity. The widespread use of *Anemopsis* tea in New Mexico in the relief of chronic, autogenic digestive tract disorders such as ulcers suggests that the beneficial properties, if any, of *Anemopsis* somehow affect human digestive physiology.

The results of the cardiac glycoside screen, while preliminary, do not weigh strongly in favor of any putative cardioactivity which has been ascribed to *Anemopsis*. While it is true that a crude MeOH extract of *Anemopsis* gave an apparent positive Kedde test, the fractions of the large-volume, more concentrated MeOH extract which seemed most likely to contain cardiac glycosides or aglycones gave either equivocal or negative results in the same test. It is conceivable that butenolide-containing compounds were originally present in the unrefined large-volume MeOH extract and that they were altered during partitioning of that parent extract into the fractions that were assayed. Moreover, because pentadienolides may give negative Kedde tests (Sim 1967), the question of whether *Anemopsis* contains cardiac glycosides cannot as yet be resolved.

It is clear that much further investigation, especially pharmacological testing, will be necessary before a definitive statement can be made regarding the potential of *Anemopsis* as a source of useful medicinal substances. On the other hand, although the known constituents are few, they include an array of compounds with possible therapeutic value, adding further interest to this traditional arid-zone "yerba."

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Resumen.--Anemopsis californica (Saururaceae) es una planta rizomatosa nativa en hábitats con húmedad y baja elevaciónes entre las zonas aridas del sudoeste Estados Unidos y partes del norte de México. Por toda su rango geográfica, la planta tiene un lugar importante en remedios caseros, especialmente como vulnerarios. Tiene usos como un estomacal, tónico cardiovasular, diurético, y suprimidor de la tos. Aqui, observaciones etnobotánica y fitoquímica sobre Anemopsis son compuestas con resultados preliminaro de investigaciones para la evaluación de potencial de la planta como medicinas útil.

Indian Ricegrass (*Oryzopsis hymenoides*): A Potentially Useful Wild Grass Adapted to Dunal Habitats[1]

Anne C. Cully[2]

Abstract.--Indian ricegrass or Oryzopsis hymenoides (Roemer and Schultes) Ricker is a native grass adapted to sandy soils in arid locations. The foliage is high in protein and makes excellent winter forage for livestock. The large, nutritious seeds germinate and grow well in deep sands. There has been a long tradition of use of Indian ricegrass by southwestern Indian people that is documented in the archeological record and in ethnographic data. Indian ricegrass has the potential for providing valuable nutritional supplements for man and forage for grazing animals in areas that would otherwise be non productive.

INTRODUCTION

Indian ricegrass or Oryzopsis hymenoides (Roemer and Schultes) Ricker is a densely tufted, perennial bunchgrass that occurs mainly on dry sandy soils throughout western North America in Canada, the United States, and northern Mexico (figure 1). It is closely related to needle grasses (Stipa), and often forms sterile hybrids with species of this genus where the ranges overlap. The blades are slender and involute. Indian ricegrass panicles are diffuse and delicate, with spikelets on long, slender pedicels. The seeds (consisteing of the caryopsis enclosed by the indurate lemma and palea) are nearly round, black or dark-brown, tipped with a short awn, and are covered with conspicuous white hairs. Indian ricegrass is frequently an important species on sand dune areas, and it reproduces entirely by seed (Hitchcock 1971, Hoover et al. 1948). The large seeds provide energy for seedlings to germinate and reach the surface from under as much as 7 cm of sand (Young at al. 1983). The seeds generally ripen in June or early July, and most of the crop falls from the plants within a two week period. The success of the crop is linked to winter and spring moisture. Good moisture later in the summer can produce a second, smaller crop of seed in September. Although seed viability is high, tested germination rates are low (Charles H. Diebold pers. comm., McDonald and Khan 1977, Rogler 1960). This has been attributed to the indurate lemma and palea surrounding the caryopsis, to embryo dormancy, and to inhibitory substances in the seed coat (McAdoo et al. 1983, McDonald and Kahn 1977, Rogler 1960, Young et al. 1983). The indurate lemma and palea seem to play the primary role in the delay of germination. Germination has been enhanced by scarification with sulfuric acid, althrough this was sometimes found to severely damage the seed (McAdoo et al. 1983, Rogler 1960, Toole 1940). In artificial seeding, seeds that are cracked during mechanical harvesting have been observed to germinate well (Robertson 1977).

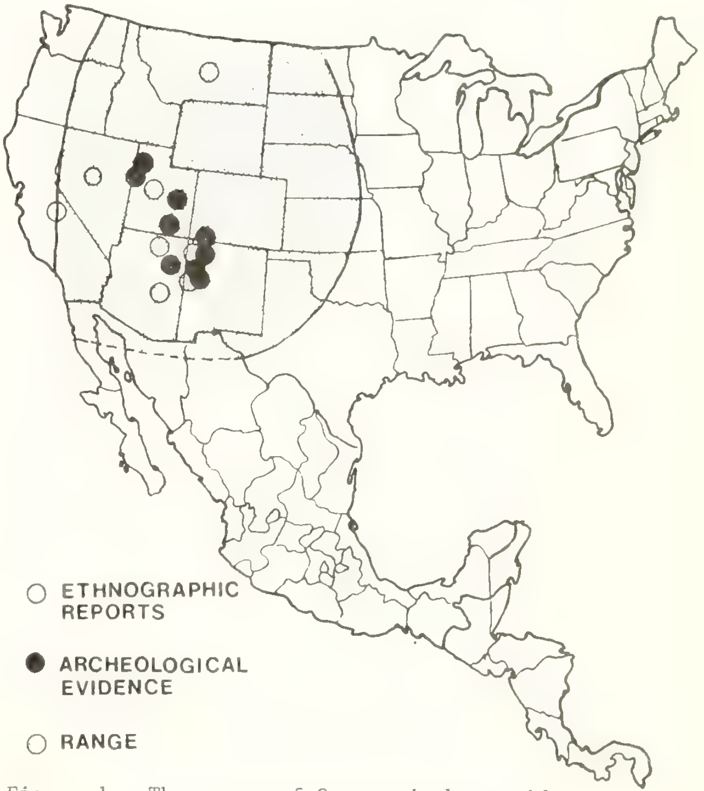

Figure 1. The range of Oryxopsis hymenoides in the western United States and Mexico; locations of ethnographic reports and archeological evidence for the use of Indian ricegrass.

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[1] Paper presented at the Arid Lands Symposium, Saltillo, Mexico.

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In Nevada, rodents were found to cache Indian ricegrass seeds in the soil; about half the seeds cached had the lemmas, paleas, and pericarps removed by the rodents. The removals greatly enhanced germination (McAdoo et al. 1983). Treatment with hormones (gibberelic acid and kinetin) also promoted germination in scarified seeds, but not in intact seeds (McDonald and Kahn 1977). Some seeds may require more than one year to reach the germination stage. Germination rates were found to increase with age up to 6 years, and gradually decrease with seeds up to 17 years old. Germination of 1 and 2 year old seed was enhanced by soaking in water at 2 - 4 degrees Centigrade for 40 days (Rogler 1960). In field conditions, seeds in all stages of seed coat deterioration and ripeness of embryo have been found in the soil under established stands (Robertson 1977). Winter precipitation and cold temperatures may provide the moisture and chilling necessary for successful germination. Artificial seeding is most successful if done in the fall before the onset of cold, wet weather (Charles H. Diebold pers. comm.).

Root systems on large vigorous plants extend up to 1.4 m downward and laterally, and provide substantial stability to loose soils (Hoover et al 1948). The deep extensive root system makes it possible for the plant to use moisture that would be unavailable to shallow rooted species. Indian ricegrass is drought resistant and tolerant of moderately alkaline soils. The grass provides good winter feed for livestock, due both to the nutritious seeds and high-protein foliage. Overgrazing (especially in the spring when the new growth and seedlings are particularly vulnerable) has considerably reduced the extent of this species over much of its range; reduction or elimination of grazing in the spring and early summer allows reproduction and food storage to take place, and the grass can then tolerate winter grazing without damage. As a forage grass, Indian ricegrass is particularly valuable in arid lands because of its capacity to grow and spread by natural processes in area where it is diffucult for other grasses to become established (Hitchcock 1971, Hoover et al. 1948, Robertson 1977).

ARCHEOLOGICAL EVIDENCE FOR THE USE OF INDIAN RICEGRASS

Indian ricegrass was also a valuable resource to prehistoric human populations in the southwestern United States. Indian ricegrass seeds and pollen that closely resemble that of Indian ricegrass have been found associated with storage and cooking features in prehistoric archeological sites in the Southwest, especially in the Four-Corners area, where Utah, New Mexico, Arizona, and Colorado meet (figure 1). Pre-agricultural hunters and gatherers from the Archaic Period (6000 B.C. - 100 B.C.) were the first people to attempt to earn a living from arid lands in the Southwest. They are thought to have relied heavily on wild plant foods and small game animals. Because of the shallow and exposed nature of many structureless archeological sites from this period, botanical remains are often poorly preserved or entirely absent. However, occaisional, reliable evidence for the use of wild plant foods has been found. In northwestern New Mexico, several deep pits associated with hearths dating to the late Archaic Period contained Indian ricegrass seeds (Table 1, Toll 1985). Botanical evidence from later Anasazi times (100 B.C. - A.D. 1300) indicates that in addition to agriculture, people continued to rely on wild plant foods as a significant proportion of their diets (see Gasser 1982). The permanent structures associated with a more sedentary lifestyle afford much better protection for botanical remains, and considerable evidence for the prehistoric use of many wild plant species, including Indian ricegrass, has been found in New Mexico, Colorado, and Utah during this period (Table 1). In some of these sites, the seeds have

Table 1. The occurrence of *Oryzopsis hymenoides* seed and pollen resembling this species in archeological sites in the southwestern United States.

	Pollen	Float
Archaic Period Sites Ca. 5000 B.C. - 100 B.C.		
NW New Mexico		
NMAP Project	+	+[b]
Anasazi and Fremont Period Sites Ca. 100 B.C. - A.D. 1200		
NW New Mexico		
NMAP Project	+	+[b]
NIIP Project	+	+[b]
Little Water		+[b]
Tsaya		+[b]
Pittsburgh Midway		+[b]
Chaco Canyon		+[b]
Salmon Ruin		+
Utah		
Danger Cave		+
Hogup Cave		+
Glen Canyon		+
Clyde's Cavern	+	+
Arizona		
Antelope House		+
Colorado		
Hoy House	+	+
Navajo Historic Sites		
NW New Mexico		
NMAP Project		

[a] Data from Bohrer 1980, Cully and Clary 1985, Fry 1975, Scott 1979, Stiger 1977, Toll 1981, 1985a, 1985b, Winter and Wylie 1975.

[b] Data summarized in Toll 1985b.

been found in a charred condition indicating parching or cooking, or uncharred in storage features or other proveniences suggesting purposeful introduction by man. Pollen from the Gramineae family is difficult to distinguish to the genus level, however, pollen that closely resembles that of Indian ricegrass has been found in archeological contexts. Both seed remains and Oryzopsis-type pollen have also been found in prehistoric coprolites (human fecal material), providing direct evidence of human consumption of this wild grass (Fry 1977, Fry and Hall 1975, Scott 1979, Stiger 1977, Toll 1981).

ETHNOGRAPHIC EVIDENCE FOR THE USE OF INDIAN RICEGRASS

Among native people in the southwestern United State, ethnographers have documented the historic importance of this species as a supplement to domesticated crops, and as a mainstay during times of poor crop production. The widespread record of human use from archeological and ethnographic data (figure 1) indicates the continuous use of this species, and also suggests the potential value of this wild crop for modern use (Jones 1938). In New Mexico, the Zuni people harvested the seeds and ground them into flour for bread. In times of food shortage, they searched the countryside to gather large quantities of the seed, and were seen bringing basketsful from as far away as 16 km (Castetter 1935, Stevenson 1915). Among the Hopi of northern Arizona, agriculture is also the primary means of subsistence, however, Indian ricegrass and dropseed grasses (Sporobolus airoides, S. contractus, S. giganteus) were regarded as staple wild plant foods. These grasses were preferred because of ease in harvesting; the ripe seeds fall readily from the plants. As with the Zuni, these grasses were especially important in times of agricultural failure. The importance of Indian ricegrass to the Hopi, at least in the past, is reflected by the naming of a clan for this species (Whiting 1939). Navajo people in northwestern New Mexico also used Indian ricegrass. The stems were gathered and the seeds collected by holding the grass near the fire. The thin pedicels quickly burned and the seeds fell to the base of a flat stone placed nearby. The seeds were then ground and made into cakes (Elmore 1944). Blankenship (1905 in Jones 1938), reported that seeds of Indian ricegrass were used by unspecified tribes in Montana. In Utah and Nevada, the Paiute people value Indian ricegrass greatly because it will grow in dry conditions in sand, and furnished food for man and forage for grazing animals. These people also traveled long distances to gather this esteemed food. The seed was ground into a meal and made into mush. The Paiute people aso used harvested seed for replanting the range (Murphey 1959, Steward 1933). The Gosiute tribe also used Indian ricegrass (Mooney 1896, Chamberlain 1911). In Arizona, the White Mountain Apache people formerly used the seeds of this grass for food, but more recently the plant has been used only for hay (Reagan 1929). In Californa, the Koso, or Panimint Indians also gathered and used the seeds of Indian ricegrass (Coville 1892).

AN EXTENSIVE DUNE AREA DOMINATED BY INDIAN RICEGRASS IN NORTHWESTERN NEW MEXICO

Actual cover values, plant densities and seed and forage yields for Indian ricegrass are scattered throughout various types of scientific literature. A study that a co-worker and I conducted in Northwest New Mexico can help to understand some of the conditions under which growth and reproduction of this species take place, as well as providing data on cover, density, and estimates of seed productivity (Cully and Clary 1982). In northwestern New Mexico, Indian ricegrass is a major component of the vegetation on extensive dunal deposits located south of the San Juan River. The dunes cover an area of about 2300 square km, and form the second largest dune field in New Mexico. The field is a thin mantle of aeolian sand with broad areas of exposed Cretaceous age sandstone and shale badlands. Much of the sand in the dune field is in the form of longitudinal dunes that trend in a northeasterly direction. Most of the dunes are between 0.8 - 3.2 km long. Distances crest to crest between dunes range from 90 - 450 m; the dunes are about 60 m wide and extend from 4 - 7 m above the interdunal surfaces. The sources of the dune sands are thought to be in-situ eroding of the sandstone beds and aeolian deposits brought by prevailing westerly winds from the adjacent Chaco river valley. The field is thought to be at least 6700 years old (Clary 1980, Hall 1970).

The dunes are well vegetated for the most part. Some are active along the crests, and recent aeolian activity occurs along the borders of the field where drainages incise. The sandy soils overlie less permeable clay or silt formations, producing excellent conditions for retaining precipitation. Moisture penetrates the upper, sandy permeable soils. The underlying impermeable layers keep the moisture from percolating to deeper levels, so that the moisture is then available for plant growth. Very little arroyo cutting is found within the field, although the area is surrounded by badland and sandstone outcrops. The elevation of the field ranges from 1757 - 1988 m. Precipitation averages about 17.8 - 25.4 cm per year. Most of the precipitation falls during late summer, but there is also an important component of winter and spring moisture (figure 2), that seems to be critical to the growth and reproductive success of Orysopsis.

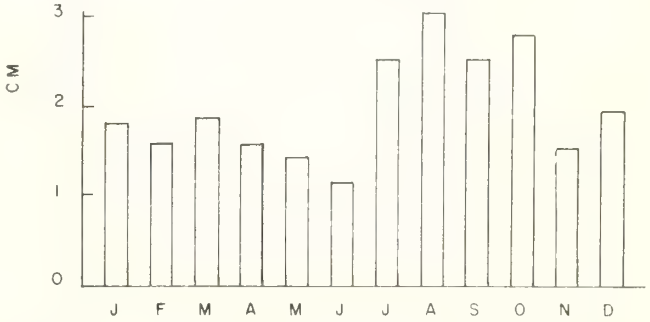

Figure 2. Monthly precipitation, Aztec Ruins National Monument, Northwestern New Mexico, 60 years of record (from Gabin and Esperance, 1977).

Our study area included approximately 37,344 ha of Navajo tribal grazing land that is being converted to sprinkle-irrigated agriculture. The water was allocated from the Navajo Dam on the San Juan River, and is carried by pipeline from river level to the higher plateau to the sourth. Our study accompanied an archeological survey and excavation that preceded road building, leveling, and grading activities, and was designed to produce data on vegetative dominants, cover, species composition, plant densities, and plant resources that may have been available to prehistoric inhabitants of the area. Our methods consisted of first stratifying, or dividing the study area into zones based on topography, soil, and constituent perennial plants. We used color aerial photography (1:3.680, Bureau of Land Management, Albuquerque Office), and USGS 7.5 minute topographic maps of the area to map vegetative zones. The sampling transects within these zones were located randomly. The line intercept method (Canfield 1941) was used to sample the vegetation because accurate and fairly complete information about a plant community can be obtained relatively quickly. Following Cox (1975) and Strong (1966), we estimated foliage cover or dominance, plant density, diversity, and frequency. We also took soil samples at the beginning and at the end of each transect.

We found that Indian ricegrass was most abundant on the dune crest and faces, while other grass species like galleta grass (Hilaria jamesii) dominate the interdune areas (table 2; figure 3). The soil samples indicated that the interdunal soils were silty sands, wheras the dunal soils were clean, coarse sands, Ricegrass appeared to be more successful in the coarser soils, and species more tolerant of fine soils were restricted to the swales between dunes.

During our survey, we also noted the presence of Indian ricegrass in all stages of growth from seedling to mature plants. Seedlings appeared to be the first plants to move into recently disturbed areas such as roadcuts, pipelines, and fences. This suggests that Indian ricegrass is an early colonizer of disturbed sandy soils and is well adapted to such conditions. This early colonizer may add substantially to soil stability and allow other species to become established later.

Based on foliage cover, Indian ricegrass was the dominant species in 6 of our 10 delineated vegetation ones (table 3), comprising most of the study area. Oryzopsis was a subdominant in 3 of the remaining 4 zones. The Oryzopsis-Hilaria-Sporobolus zone contained by far the highest cover and densities of Indian racegrass plants (table 3), almost 10 plants per square meter or 1000,000 per ha. This area is actually a small proportion of the total (table 3), but would have been an ideal area for prehistoric people to gather seed. Because of the high plant densities, there would be maximum reward for a minimum of energy expended in gathering. Based on estimates of seed production from other locations, this portion of the study area may produce aproximately 116 kg of seed per ha (table 4). There are few comparable productivity data; what there are suggest that there is a great deal of variability between geographic locations, as well as high temporal variability. Plant densities were considerably lower at a study area in central Utah (Larralde and Chandler 1981); actual seed production was also lower than our estimates for northwestern New Mexico. During a year of favorable conditions in Nevada, the yield for about one-fifth the number of plants per ha was alomst one-half the estimated yield in New Mexico (table 3; Young et al. 1983) suggesting that our estimates may actually be low.

Indian ricegrass is grown commercially, primarily for range reseeding and revegetating stripmined areas. While no plant densities are available, seed production data are (table 4). At Los Lunas, New Mexico, the mean of 13 years of production under cultivation (including irrigation and fertilizing at the rate of 100 lbs of ammonium nitrate per acre), was 620 kg per ha (Charles H. Diebold, pers. comm.). The data from northwestern New Mexico and Nevada suggest that, under suitable conditions, yields from untreated locations can be quite high,

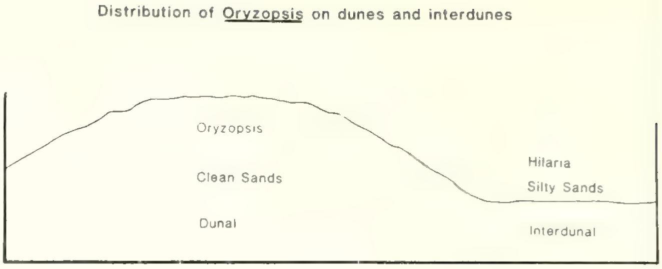

Figure 3. Distribution of Oryzopsis hymenoides in dunal habitats, northwestern New Mexico (from Cully and Clary, 1982).

Table 2. Centimeters of cover of 2 species from fine, interdunal soils to coarse, dunal sands along Transect 4, NIIP Blocks VIII-XI, northwestern New Mexico (from Cully and Clary 1982).

	Interval along transect - fine to coarse soils					
Species	1	2	3	4	5	Total
Oryzopsis hymenoides	84	46	148	179	249	706
Hilaria jamesii	22	21	33	0	0	90

Table 3. Total percent foliage cover, percent foliage cover of *Oryzopsis hymenoides*, density of *Oryzopsis* plants and percent of total area of each zone, NIIP Blocs VII-XI, northwestern New Mexico (from Cully and Clary 1982).

Zone	% Total Foliage Cover	% Foliage Cover *Oryzopsis*	Density per M^2 *Oryzopsis*	Percent of Total Area
Or-Ep-Hi	39.4	17.6	3.0	8.7
Or-Sp-Sa	38.4	14.1	3.5	1.5
Or-Hi-Sp	37.7	27.6	9.7	0.8
Or-Hi-Ep	33.3	12.2	4.0	44.6
Hi-Bo-Or	31.5	4.0	1.2	7.8
Hi-Or-Gu	30.3	8.2	5.5	18.7
Sp-Ep-Ta	24.6	1.0	0.3	2.4
Or-Mu-Hi	23.2	9.2	1.6	1.0
Hi-At-Or	7.8	1.3	0.6	0.6
Or-Ep-Bo	33.6	12.6	3.4	14.0

Or = *Oryzopsis*
Hi = *Hilaria*
Sp = *Sporobolus*
Bo = *Bouteloua*
Gu = *Gutierrezia*
At = *Atriplex*
Ep = *Ephedra*
Ta = *Tamarix*

Table 4. Seed and forage yield estimates for *Oryzopsis hymenoides*.

	Cultivated			Uncultivated	
	Forage (kg/ha)	Seed (kg/ha)		Forage (kg/ha)	Seed (kg/ha)
Los Lunas, N.M.[1] 13 yr period		mean = 642.0 SE = 22.9	N.W. New Mexico[3] Estimates based on densites, one dunal site (9.7 plants/m^2)		116.0
Utah[2] various ecotypes	452-5762		Utah[4] Yield on dunal site (0.5 plants/m^2)		10.3
			Utah[5] 3 yr period	mean = 25.6 SE = 9.7	
			Nevada[6] Desert Queen Valley, 1 yr (1.7 plants/m^2)		63.8

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[1] Charles H. Diebold, pers. comm,

[2] Robertson 1977

[3] Cully and Clary 1982; Vogler 1982

[4] Robertson 1977

[5] Young et al. 1983

although irrigated and fertilized fields produce substantially larger quantities of seed.

Data on forage production also indicate substantial increases under cultivation (table 4). Geographic and temporal variability no doubt affect uncultivated forage as well as seed yields.

A REVIEW OF THE NUTRIENT VALUE OF INDIAN RICEGRASS

Several analyses of the constituents of Indian ricegrass indicate that the traditional value placed on this species is justified. The seeds are high in protein and calories, exceeding or equivalent to corn; the protein value of the forage is also high (table 5); the cured grass makes very good hay (Hoover et al. 1948). The seeds of other cultivated grasses (Sorghum sudanense, Secale cereale, Triticum aestivum, Zea mays; see table 5) are similar in protein values, but also have larger seeds and higher carbohydrate values. Most cereal crops are highly productive annuals, and have been selected over a long period of time for large seed size and high carbohydrate content. Indian ricegrass is a wild perennial grass that, in comparison to cereal crops, has undergone very little human selection.

Seed size and productivity may be improved by controlled breeding and hybridization, but production probably cannot reach the levels of the annual cereal crops. However, Oryzopsis will grow where other grasses cannot survive, and has the potential for productivity on otherwise unproductive land.

SUMMARY

Indian ricegrass is a native plant adapted to sandy soils in arid locations. The foliage is high in protein, and makes excellent winter forage for livestock. The large, nutritious seeds germinate and grow well in deep sands. With proper management, stands of Oryzopsis will reseed themselves naturally.

There has been a long tradition of use of Indian ricegrass by southwestern Indian people that is documented in the archeological record and in ethnographic data from the late 1800s and the early 1900s. Modern analyses of nutritional value indicate that this long tradition of use is justified. Indian ricegrass has the potential for providing valuable nutritional supplements for man and forage for grazing animals in areas that would otherwise be non-productive.

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Table 5. Protein and caloric values of Oryzopsis hymenoides and some other grasses[1].

	Wt/1000 seeds	% Protein	Calories/g	% Carbohydrate
Oryzopsis hymenoides	2.4	Seed = 11.9-13.1 Foliage = 6.5-17.0	4058	25-39
Sorghum sudanense	7.7	11.9		
Triticum aestivum		14.2		
Secale cereale	20.7	17.1		
Zea mays	App. 400.0	10.0	4020	70

[1] Data from Earle and Jones 1964, FAO 1953, Jones 1930, Kelrick and McMahon 1985, Schery 1972, Wolfe et al. n.d.

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Resumen.--Indian ricegrass Oryzopsis hymenoides (Roemer and Schultes) Ricker es una gramínea nativa adaptada a suelos arenosos en locales aridos. El follaje es alto en proteína y hace un forraje de invierno excelente para la ganadería. Las grande, nutritiva semillas germinan y cresen bien en arenas profundas. Habido una larga tradición del uso de Indian ricegrass por los Indios de suroeste que es documentado en recuerdos de arqueología y en datos etnográficos. Indian ricegrass tiene el potencial para proveer suplementos valiosos y natritivos para animales de pasto en areas que falta de oer productivas.

Values and Uses for Mesquite[1]

S. Clark Martin[2]

Abstract.--Live mesquite can provide food and shelter for wildlife, domestic livestock and man but may displace more efficient plants in the process. Mesquite wood has many uses including domestic fuel and a possible source of energy for industry. To be economical mesquite products must compete successfully with available alternatives.

INTRODUCTION

Values and uses for mesquite include those of living plants and those of products derived from harvested mesquite. Living mesquite provides forage for domestic animals, habitat for wildlife, nectar for honey bees and protection from sun and wind for a variety of creatures. Also, mesquite pods have long been staple food items for desert peoples.

Mesquites (Prosopis spp.) occupy about 34 million ha of rangeland in the southwestern United States. Of this, some 22.7 hectares are in Texas, 1.62 in Oklahoma, 9 in New Mexico and Arizona and a smaller area in southern Nevada and California (Dahl 1982). The geographic distribution of mesquite apparently has not changed greatly within the last 150 years but it has increased greatly in density and cover within its range. Fluctuations in climate and in populations of rodents and rabbits, together with reduced incidence of range fires and heavy grazing by livestock have contributed to mesquite increase. In my view, the major influences are reduced density of perennial grass stands due to overgrazing and reduced incidence of fire.

Mesquite is found within the rainfall range of 8 to 75 cm, or more, from the western deserts of California to more mesic sites in Texas. Size of tree, and number of trees per hectare generally increase with rainfall or with available soil moisture. Growth form is also influenced by soil properties. It grows best on deep, well drained soils and does poorly where roots encounter dense, rocky clay near the surface. The largest mesquite are found along water courses and on flood plains where roots have access to available moisture most of the year, especially where roots reach the water table. On upland sites that do not receive runoff and where annual rainfall is less than 50 cm, deep relatively sandy soils produce the largest trees but soils of finer texture grow more and bigger trees where rainfall is higher.

Mesquites are deciduous, thorny trees or large shrubs of the legume family. They are among the most evident and significant plants of arid and semiarid environments on both sides of the Mexico-U.S. boundary. All mesquites belong to the genus Prosopis but authorities don't agree whether the recognized subgroups are species or varieties. Benson, in Benson and Darrow (1981), states that "...character combinations of mesquite populations are inconsistent, amazing and bewildering. Regardless of speculation concerning the origins of the present populations, they interbreed, and their distinctions are inconsistent." Benson includes all mesquites in P. juliflora (Swartz) D.C. and distinguishes five varieties (Table 1). On the other hand, Johnston (1962) distinguishes three species; velutina, glandulosa, and articulata. Benson states that "Questions of classification are rarely settled, and this one never will be." Thus, the common names for the generally recognized sub-populations of mesquite are more persistent and stable than their Latin equivalents.

VALUES AND USES OF LIVE MESQUITE

Mesquites vary greatly in growth form and occur in stands of varying densities. The uses that are made of these stands, or of individual trees, depend not only on the character of the mesquite but on the products people obtain from them. Mesquite is valued for livestock forage, food production and environmental enhancement. These positive values often are offset to some extent by negative attributes or influences.

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[1] Paper presented at the reunion sobre manejo y utilizacion de las plantas aridas (meeting on management and utilization of arid land plants. [Saltillo, Coahuila, Mexico, February 18-22, 1985]

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in other ways, was a staple food with the Pimas and still is eaten by them to some extent. Fermented Pinole was a favorite intoxicating drink."

Recent evaluations of mesquite pods for human consumption indicate that the protein content of the seed is similar to that of soybean but higher than some other legumes (Zolfaghari and Harden 1982). Proximate composition of mesquite beans were determined by these authors (Table 2). Feeding tests showed that mesquite seeds provided nitrogen sufficient not only for maintenance but for partial growth of weaning rats. Mesquite beans were considered to be good sources of Ca, Mg, K, Fe, and Zn. Becker (1982) found protein from mesquite seed was deficient in sulfur amino acids but generally similar in nutritive value to other common legumes. On the other hand, pod pericarp contained little protein and was considered valuable mainly for its unique taste and high fiber content.

Table 2. Proximate composition of mesquite beans (From Zolfaghari and Hardin).

Sample	Components (dry weight basis)				
	Protein (n x 6.25)	Crude fat	Ash	Crude fiber	Total carbohydrate
	- - - - - - - - - (Percent) - - - - - - - - -				
Green fruit	13.26	2.23	3.88	35.33	80.63
Mature fruit	13.35	2.87	3.40	24.73	80.38
Seed	39.34	4.91	3.61	6.86	52.14
Pericarp	7.02	2.08	3.62	29.63	87.08

Meyer, Becker and Neukom (1982) divided mesquite pods into major fractions, determined their major chemical components and listed possible uses for each (Table 3). They prepared "acceptable" cereal products such as bread and cookies that contained Prosopis fractions. Lack of starch in Prosopis pods required addition of starch from other sources. However, they felt that addition of Prosopis flour could enrich diets where the staple foods such as casava are nutritionally poor. The word "acceptable" as used earlier in this paragraph suggests that, for most of us, food products prepared from mesquite pods would be novelties rather than foods of choice.

The most widely used food product derived from mesquite is honey. Mesquite is rated by many bee producers as the most valuable honey plant in Arizona. Consequently, beekeepers are opposed to large scale mesquite control projects designed to increase grass production.

Available data on production of mesquite pods is limited. Cornejo et al. (1982) report that production of mesquite beans is strongly correlated with crown diameter within the rainfall range from 111 to 280 mm per year. Using the average number of pods per tree over a period of two or more years, they established the equation $Y = 593.44 x - 1033.57$ ($r = 0.823$) where Y is the number of pods/tree and x is crown diameter of the tree in meters. They estimate that a mature orchard with 118 trees/ha with crowns 8 m in diameter would yield 2300 kg/ha of pods per year. To obtain such yields would require irrigation as yields of velvet mesquite pods on upland sites with 300 mm annual rainfall has been reported to be about 14 kg/ha (Barth and Klemmedson, 1982; Parker and Martin, 1952).

Environmental Enhancement

The visual quality of unbroken grassland is improved by scattered trees or patches of mesquites. The grass-mesquite complex provides visual variety and the trees offer shade for livestock and

Table 3. Fractions of Prosopis pods: main components and possible application (From Myer, Becker and Neukom 1982).

Fraction A	Fraction B	Fraction C	Fraction D
Exo-mesocarp 55%	Endocarp 25%	Endospermsplits 10%	Cotyledon 10%
Main Components			
Sucrose 30-40% Fiber 15-20%	Fiber 35-45% Protein 8-12%	Galacto-Mannan 50-70%	Protein 60% Fat 8-12%
Possible Application			
Ethanol Production Sucrose Extraction Food Products	Food Products	Gum	Protein Concentrate

Table 1. Geographic distribution of the common varieties of mesquite, Prosopis juliflora (Swartz) D.C. in the United States and Mexico (From Benson and Darrow 1981).

Common Names	Variety Name and Distribution
Mesquite	var. juliflora; Mexico and the West Indies. Not in Continental U.S. except by introduction.
Velvet mesquite	var. velutina (Wooton) Sarg.; Arizona to northern Sonora.
	var. articulata (S. Wats.) Wiggins; Southern Baja California and west central Sonora. Similar to velvet mesquite except the pods are compressed and constricted between the seeds.
Western honey mesquite	var. Torreyana L. Benson; south central and southern California; southwestern Arizona; southwestern New Mexico; along the Rio Grande from El Paso to the Big Bend in west Texas; Baja California to Sinaloa and the northern Mexico Plateau.
Honey mesquite	var. glandulosa (Torrey) Cockerell; southwestern Colorado to Kansas, Texas and northeastern Mexico.

Livestock Forage

The flowers and pods of mesquite are relished by domestic livestock. Flowers provide forage for only a short time but pods may be consumed over a much longer period since pods can be picked up off the ground long after they mature. However, cattle and horses can develop serious digestive problems if forced to subsist entirely on dried mesquite pods. On many ranges pods are an unreliable forage crop at best because production varies greatly from year to year. Mesquite leaves are not highly palatable but are relatively high in nitrogen, and therefore nutritious. Regrowth from stumps provides some forage even in areas that have been cut over. The value of mesquite as a browse plant is limited because it is deciduous and does not provide green foliage during winter and early spring when grasses are most deficient in nutrients.

Cattle do not thrive on a diet of mesquite alone except for brief periods when flowers and/or fruits are available. Historically, however, mesquite leaves have served as maintenance forage and kept animals alive in late spring after grass forage was gone. In southern Arizona, for example, where 90 percent of the perennial grasses forage is produced during the summer months, the old grass forage often was eaten up by late winter long before July rains brought new growth. In this situation mesquite that leafed out in April or May was a lifesaver. In some years flowers and pods added strength to the diet a few weeks later.

The value of mesquite forage is usually offset entirely, or partly, by reduced grass production. Several studies on the Santa Rita Experimental Range in Arizona show dramatic increases in grass production following mesquite control. Park and Martin (1952) showed that average yields of perennial grasses, 1941-1948, were 58 kg/ha in mesquite stands and 122 kg/ha where all mesquite was killed. Martin (1963) thinned 0.8 ha plots to leave varying numbers of mesquites at four sites ranging in mean annual rainfall from 30 to 43 cm in 1945. Fourteen years after treatment grasses on completely cleared plots outyielded the full stands by 4 to 6 times at the two higher rainfall sites and by 10 to 13 times at the lower rainfall sites. At the lowest rainfall site the 62-tree per ha plot produced only one fifth as much perennial grass as the 0-tree plot. At the three higher rainfall sites yields on the 62-tree plots were about 44 percent of those for plots completely cleared. These were closely controlled tests where mesquite was relatively dense and evenly spaced and follow-up treatments prevented reestablishment of mesquite on the thinned and cleared plots.

In pasture-wide tests where control was not complete and where initial stands were spotty the responses of grasses following mesquite control were less dramatic. Cable and Martin (1975) reported that cleared pastures produced 52 percent more perennial than mesquite infested pastures. In another study (Martin and Cable 1974) mesquite control increased perennial grass production by 43 percent. These increases are similar in magnitude to those reported by Dahl (1982) for various tests in Texas where aerial spraying with 2,4,5-T was the usual control method and where the reduction in density and crown cover of mesquite was variable. Dahl reported that increases in grass production increased with the degree of control, but that under the more mesic conditions in Texas 62 mesquites/ha had little impact on grass production. In Arizona, 62 evenly spaced mesquites per ha reduced grass production by half.

Rational decisions on the merits of mesquite control must weigh the advantages of having emergency forage at the time when grasses most often are deficient in quantity and quality against the possibility that there might be more than enough grass forage to carry the animals if the mesquite were not there. An obvious compromise would be to leave a few widely spaced mesquites or scattered patches. The mesquite could provide emergency forage and shelter from sun and wind without seriously reducing forage production.

Food for Human Consumption

A brief summary of human uses for mesquite is provided by Kearny and Peebles (1953):

"This plant has been a mainstay of existence to the aborigines of the Southwest. When cultivated crops failed, the Indians subsisted mainly on mesquite beans. Pinole, a meal made from the long sweet pods prepared in the form of cakes and wildlife, perching and nesting sites for birds and escape cover for deer, peccary and other wildlife.

Mesquite also enriches the soil, at least locally. Tiedemann and Klemmedson (1973) found that organic matter, total nitrogen, total sulfur and total soluble salts were up to three times greater in the surface 0 to 4.5 cm of soil under mesquite crowns than in soil in openings and that bulk density under trees was lower. Jarrell et al. (1982) reported that symbiotic N fixation by mesquite is widespread, makes substantial inputs into mesquite-dominated ecosystems, and recommended that mesquite should be innoculated if planted where suitable indigenous rhizobia do not exist. Shoustari and Pepper (in press) in Arizona found that indigenous bacteria associated with mesquite were more aggressive in entering root hairs and fixed more nitrogen than did commercially available mesquite innoculant.

Barth and Klemmedson (1982) found that velvet mesquite accumulated N at the rate of 11.2 g/m^2 per meter of height and C at the rate of 0.11kg/m^2 per meter of height. These findings help explain the greater abundance and improved growth of perennial grasses observed under mesquite. Tiedemann and Klemmedson (1977) found cover of perennial grasses under velvet mesquite was 24 percent compared to 4 percent in the open. Similarly perennial grass biomass was 1146 and 239 kg/ha in canopy and open zones, respectively. However, since less than 20 percent of the area is covered with mesquite the weighted average biomass would be no more than 420 kg/ha. Average perennial grass production for several years on mesquite-free plots at two similar sites was 552 kg/ha Parker and Martin (1952).

There can be little doubt that mesquite in the presence of suitable rhizobia can and does fix atmospheric nitrogen although nodules indicating presence of nitrogen fixing bacteria are rarely found on mesquite growing naturally. The fact that soil under mesquites is more fertile than soil in the openings is also indisputable. However the evidence is strong that much of the increased fertility under mesquites is attained by draining nutrients from nearby openings. Soil under mesquite crowns is enriched by leaf fall and by organic matter swept from spaces between trees by the wind. Also, mesquite roots extend far beyond the edge of the crown and gather both moisture and nutrients from the openings. In most mesquite stands these processes enrich less than 20 percent of the soil surface at the expense of the remainder. It is by no means certain that symbiotic nitrogen fixation by mesquite results in a net gain in the nitrogen economy of grassland soils as mesquite invades.

Afforestation

I have had the experience of showing scientists from such areas as India and Pakistan the detrimental effects of mesquite on the Santa Rita Experimental Range only to receive a letter sometime later requesting mesquite seed for planting. These requests come from areas where fuel for domestic use is very scarce and there is a real need for any kind of a plant that will produce wood for cooking fuel or other domestic use.

Mesquite (P. juliflora) is being evaluated for sand dune stabilization in Saudia Arabia (Abohassan 1978). This seems to be a logical application since sizeable tracts in Arizona and New Mexico are occupied by mesquite sand dunes.

Negative Attributes

The primary objection to mesquite where it occupies former grassland is that ground cover is reduced and erosion is accelerated. Martin[3] found that mesquite control reduced the rate of loss of surface soil by two thirds during the period from 1974 to 1983. Reduced surface erosion was also reported by and Parker and Martin (1952). Reduced ground cover lets non-forage plants become established in space previously occupied by grasses. Mesquite generally makes the site drier and reduces the amount of moisture available to prime forage plants. Mesquite competition is especially severe during the late spring and early summer when mesquite leafs out on accumulated cool-season moisture long before the warm-season perennial grasses begin rapid growth. Moisture used by mesquite at this time creates a moisture deficit that must be replenished by early summer rains.

The detrimental effects of mesquite on grass forage production is often aggravated by increases in populations of rabbits and rodents. These small animals can consume enough forage and seed on seriously depleted ranges to greatly retard or prevent restoration of the grass stand even if domestic animals are removed. Moreoever, as the process of deterioration continues, the quantity of available grass decreases and domestic animals are forced to rely more and more on mesquite.

VALUES AND USES FOR HARVESTED MESQUITE

Mesquite may be harvested for use on the site or transported to other locations for processing and use. Since mesquite on the range has been considered a weed rather than a crop few measurements of standing biomass or annual production are available. Barth and Klemmedson (1982) determined the distribution of dry matter (Table 4) which suggests the yield of dry wood from velvet mesquite to be 22 metric tons/ha on an upland site in Arizona with 30 cm annual rainfall. Cornejo et al. (1982) estimated wood yield in the Alter Valley southwest of Tucson to be 12 metric tons per hectare for riparian habitats and 5 metric tons/ha on non-riparian sites.

In a review of available data for the Texas Rolling Plains Dahl (1982) reported that dry wood production by mesquite was about 2, 12, and 22 metric tons per hectare for shallow upland, deep upland and bottomland sites respectively. These one-time yields tell us nothing about annual yields or rate of regrowth. Dahl also cites a report by Wright and Stinson (1970) which indicated that annual growth on uncut trees was about 1.8 kg compared to 0.4 kg on trees with tops removed. Assuming 600 trees per hectare this would amount to 1080 kg/ha on uncut trees compared to 240 kg/ha of regrowth from stumps. There is a real need for better information on actual and potential yields of wood from mesquite throughout its range.

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[3] Martin, S. Clark, unpublished data from Santa Rita Experimental Range.

Table 4.--Amount and distribution of dry matter in 34 velvet mesquite trees with average height 3.3m and crown area 20.9m^2. Dry matter per ha values assume 200 plants/ha (From Barth and Klemmedson 1982).

Component	Kg/shrub	Kg/ha
Shoot		(200 plants)
Leaves	3.24	648
Flowers	0.04	8
Fruit	0.07	14
Current twigs	0.26	52
Small branches (<1cm)	8.25	1,650
Large branches (>1cm)	75.92	15,184
Deadwood	26.36	5,272
Subtotal	114.14	22,828
Roots	15.44	3,088
Total Plants	129.58	25,916

Raw Wood

Seasoned mesquite wood is commonly used for fence posts, domestic fuel, furniture, crafts, and construction in buildings, corrals, even fishing boats. Heartwood of mesquite is dark brown, moderately hard and has been used for many products that commonly are made of walnut. Examples include furniture, gunstocks, craft items. Mesquite has limited use in construction because most stems are not long enough and straight enough for lumber. Even so, I saw mesquite used for construction of the frame work for fishing boats at Punto Penasco, Sonora. Slabs of mesquite were keyed together to form the framework.

Processed Wood

There is a rather large market for charcoal in the United States. A number of specialty restaurants even in the Northeastern U.S. feature mesquite-broiled steaks. Mesquite could provide much more of the charcoal for backyard barbequeing than it now does.

Mesquite wood may also be ground and processed into feed for cattle where it may be substituted for cottonseed hulls or similar roughage (Bryant et al. 1982; Tock 1982). Wood molasses may also be derived from mesquite and used as a forage supplement. Other products that may be made from mesquite include paper and particle board. Chemicals include: gums, tannins, alcohols or derived medicines (Parker (1982). All of these uses for mesquite are technically possible but most of them are not economically feasible at present.

Mesquite is being evaluated as a source of energy for industry. Two possibilities include: (1) petroleum extraction (Parker (b) 1982) and (2) generation of electricity (Smith 1982). A major shortcoming of mesquite for such industrial uses is the low yield of wood. Mesquites, generally, yield a small amount of wood per tree, stands are often sparse and harvesting costs are high.

A mobile mesquite harvester designed to cut whole trees at the ground surface reduce them to small pieces or chips and elevate these into a basket where they can be dumped into a truck has been pilot tested (Ulich 1982). The cost of harvesting green mesquite with this machine is estimated to be $8.21 per 1000 kg of green wood; about half the cost for other methods now in use.

CONCLUSIONS

Mesquite generally reduces carrying capacity for livestock, accelerates sheet and gully erosion, and increases the cost of handling range livestock. I feel that mesquite control is an essential range management practice just as weed control is necessary in row-crop agriculture.

The essential demands for live mesquite for emergency forage, honey production, wildlife habitat, shade and scenic beauty usually can be met with much less than a full and complete stand of mesquite. Scattered trees and/or alternating patches of mesquite and open grassland may be the best multiple-use compromise.

The current value of mesquite wood for domestic and/or industrial use doesn't always pay the cost of harvesting. Such uses may be feasible, however, if increased forage production offsets part of the harvesting costs. Conversely, returns from the sale of wood may make mesquite control feasible for range improvement.

The use of mesquite pods for human food is more novel than practical except in primitive cultures during periods of extreme food scarcity and where mature stands of mesquite already exist. Where mesquite stands must be established, the need for wood for domestic use may be so great that mesquite trees will be cut for fuel long before they are old enough to bear high yields of pods.

With effective promotion the market for mesquite wood chips and/or charcoal for home and restaurant barbeque cooking in the United States can probably be expanded.

As with other commodities the market for mesquite wood, for whatever purpose, will be strongly influenced by the availability, cost and quality of competing products.

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Resumen.--Mezquite puede proveer comida y resguardo para fauna sylvestre, ganaderia y humano pero tambien puede desplazar plants que son mas eficiente en el proceso. Leña de mezquite tiene muchos usos incluiendo combustibles domésticos y como alternativa de energía para industria. Para acer económico, productos de mezquite tienen que competir con buen éxito con disponible alternativos.

Alternativas de Industrializacion de la Gobernadora[1]

Baldemar Motomochi B.[2]

Resumen.--La gobernadora (Larrea tridentata) es un recurso de gran abundancia en las zonas áridas y semiáridas de México. En el presente trabajo, se presentan algunas generalidades de este recurso y los diferentes usos potenciales para el mismo. Se presentan tambien dos opciones de industrialización que estan siendo estudiadas en el Centro de Investigación en Química Aplicada (CIQA), los resultados obtenidos y las conclusiones al respecto.

INTRODUCCION

La gobernadora, nomore descriptivo utilizado en México para la Larrea Tridentata, es una de las plantas características y de mayor abundancia en las zonas deserticas y semideserticas del país.

La gobernadora es una planta que presenta diferentes aspectos de gran interes que van desde los complejos mecanismos fisiológicos y sofisticadas estra tegias defensivas, base de su gran capacidad de adaptación, hasta el gran número de posibilidades que este recurso ofrece como fuente potencial de materias primas en la elaboración de productos diversos de uso industrial ó final.

Un considerable esfuerzo do investigación ha sido desarrollado en diferentes instituciones nacionales e internacionales, que ha permitido elevar el conocimiento sobre este recurso y establecer las bases para la busqueda de opciones de industrialización.

LA GOBERNADORA COMO FUENTE DE MATERIAS PRIMAS Y MATERIALES

El arbusto de gobernadora tiene una gran variedad de sustancias químicas tales como ceras, compuestos volátiles y compuestos fenólicos. Se reportan más de cien compuestos químicos identificados de los cuales el 83 at 91% son de tipo fenólico (Lignanos y Flavonoides).

Además de los compuestos químicos presentes, este recurso ofrece otros materiales de interés como lo son el material celulósico y las hojas que contienen un nivel importante de proteína (16-19%).

Existen antecedentes de la utilización de este recurso con fines comercia les tal como lo fué la obtención de ácido Nordihidroguayarético (NDGA) para su uso como antioxidante en grasas, vitámina A, salmón, etc. El NDGA fué producido por 25 años a partir de Gobernadora hasta que en 1942 fué declarado producto dañino para la salud por la FDA en Estados Unidos.

USOS POTENCIALES

En la figura 1 se muestran las diferentes opciones técnicas de utilización de las sustancias y materiales presentes en la Gobernadora. En esta figura se resumen los diferentes usos posibles para este recurso, de acuerdo a investigaciones llevadas a cabo por diferentes instituciones en México y otros países.

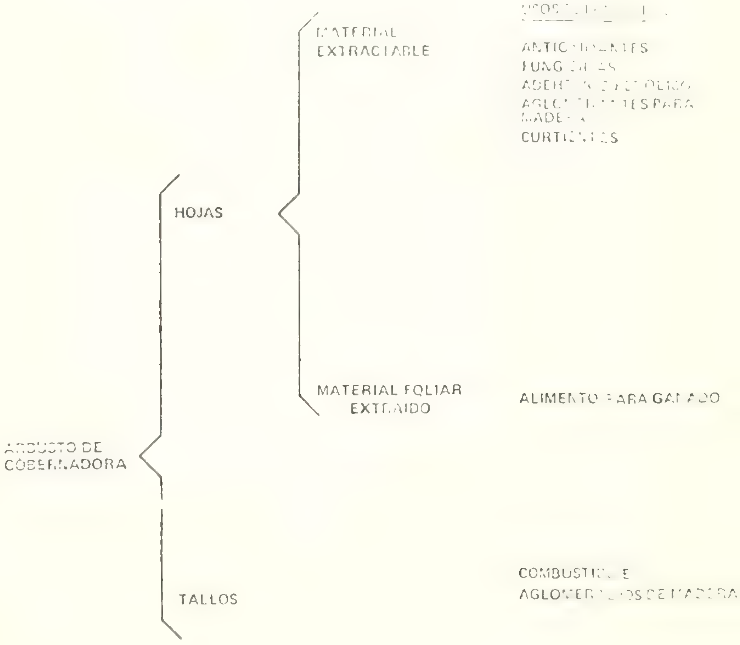

FIGURA 1. USOS POTENCIALES REPORTADOS PARA LOS DIFERENTES MATERIALES PRESENTES EN EL ARBUSTO DE GOBERNADORA

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[1] Ponencia presentada en la Reunión Sobre Manejo de Plantas en Zonas Aridas. Saltillo, Coahuila, México. Febrero 18-22, 1985.

[2] Ing. Químico, Jefe del Depto. de Ingeniería y Desarrollo del CIQA, Saltillo, Coahuila, México.

OPCIONES DE INDUSTRIALIZACION

El aprovechamiento industrial de la Gobernadora plantea una serie de aspectos que deben tomarse en consideración para el diseño de las opciones téonicas y económicas en dicho aprovechamiento. Entre estos aspectos se pueden mencionar los siguientes:

-- La Gobernadora es un recurso silvestre aún no domesticado disperso en el 25% del territorio nacional.

-- Las operaciones de recolección, densificación y transporte de recursos silvestres con contenidos bajos de los materiales de interés, normalmente involucran altos costos y requieren de una buena organización para cubrir satisfactoria y oportunamente las necesidades de abastecimiento.

-- La gran cantidad de compuestos químicos presentes en la Gobernadora impone serias restricciones para su aislamiento y recuperación en productos puros.

-- La economía de escala en los sistemas de producción en base a recursos naturales silvestres del tipo de la Gobernadora, se ve reducida al no poderse contar con instalaciones de gran capacidad dado que se incrementaría notablemente el esfuerzo de transporte (radios de acción mayores) y el costo de la materia prima puesta en planta.

Ante estos y otros muchos factores a considerar, se requiere de la definición de una estrategia que permita minimizar las desventajas y maximizar los beneficios para hacer factible técnica y economicamente la explotación industrial del recurso.

Tomando en consideración alguno de los aspectos antes mencionados y fundamentandose en información generada a nivel laboratorio, el CIQA ha venido realizando algunos programas de investigación y desarrollo tendientes a encontrar opciones para la industrialización de la gobernadora. Básicamente se ha venido trabajando en dos opciones; la obtención de resina de Gobernadora para su utilización como antioxidante de hules y plásticos y, la obtención de resina de Gobernadora para su utilización como curtiente de pieles.

RESINA DE GOBERNADORA COMO ANTIOXIDANTE DE HULES Y PLÁSTICOS

Diferentes pruebas de aplicación han sido llevadas a cabo y en las que se ha demostrado que la resina de Gobernadora puede ser utilizada como anti oxidante de hules y plásticos (hule natural de Guayule, SMR-5, NATSYN, PB, SBR y polietileno) tanto en su almacenamiento como en la elaboración de productos terminados. Se ha encontrado una equivalencia con productos comerciales tales como el T.Q.P., BLE 25, AMINOX 25, etc.

Paralelamente a las evaluaciones de aplicación del producto se realizaron estudios del proceso de extracción y purificación de la resina de Gobernadora como antioxidante. Mediante el proceso desarrollado se pretende fraccionar la resina de Gobernadora contenida en las hojas y utilizar unicamente el extracto alcoholico de la misma.

Se han realizado estudios complementarios (mercado, costos, disponibilidad de materia prima, etc.) que han permitido hacer análisis preliminar de la factibilidad de instalación de una unidad industrial de producción con una capacidad de 1000 toneladas de resina antioxidante por año. Dicha capacidad fue establecida en base a la posibilidad de exportar el producto al mercado Europeo y en la cantidad de materia prima disponible en un área aproximada de 8000,000 Has. estudiada para abastecer a dicha planta.

Los analisis económicos realizados sobre esta opción permiten establecer los siguientes puntos:

-- La rentabilidad en la producción de 1000 toneladas por año de resina antioxidante es baja, si se considera a la resina como el unico producto de valor comercial.

-- Derivado del punto anterior, es necesario aprovechar los subproductos de proceso, principalmente la hoja (4,200 tons/año).

-- Poblaciones de mayor concentración en el recurso silvestre podrían reducir notoriamente los costos de la materia prima puesta en planta y por lo tanto el costo de producción (la materia prima, hoja de Gobernadora representa alrrededor del 40% del costo de producción).

Actualmente se realizan investigaciones sobre las posibilidades de utilizar la hoja desresinada en la alimentación de animales, para ver las posibilidades técnico-económicas que una unidad industrial de producción pudiera tener en terminos de un aprovechamiento más integral del recurso.

RESINA DE GOBERNADORA COMO CURTIENTE DE PIELES

Durante 1983 México importó 10,455 toneladas de curtiente de origen vegetal que cubrieron las necesidades de la industria de la curtiduría. En 1981 se importaron 17,164 toneladas del mismo material (Quebracho y Mimosa).

Actualmente este sector industrial a reducido notoriamente su capacidad en la curtición de pieles, debido principalmente a la imposibilidad de importar estas materias primas al ritmo y cantidades requeridas para su operación normal.

Pruebas llevadas a cabo a nivel laboratorio sobre la obtención de resina curtiente a partir de Gobernadora, así como pruebas de aplicación de la resina obtenida, han establecido las bases para el estudio de una nueva opción de aprovechamiento industrial de este recurso.

Análisis preliminares de las posibilidades técnico-económicas de esta ópción muestran mejores perspectivas para la resina de gobernadora curtiente que los encontrados para la resina de gobernadora antioxidante. Los trabajos de investigación y desarrollo planteados para el año en curso, así como estudios adicionales que se realizarán, permiten suponer que para finales de este mismo año, podrá ser posible conocer la factibilidad de producir a nivel industrial, resina de gobernadora curtiente.

CONCLUSIONES

La Gobernadora es un recurso natural que ofrece un gran número de opciones para su aprovechamiento. La gran variedad de productos químicos presentes, representan un gran reto a la capacidad técnica y al diseño de opciones para su industrialización y generación de productos con interés comercial.

En el caso de las dos opciones presentadas, el aprovechamiento de los subproductos principalmente el de la hoja desresinada, es determinante para la obtención de mayores margenes de utilidad que hagan más atractiva la instalación de unidades industriales de producción.

En base a los resultados y evaluaciones hechas sobre estas opciones y a la experiencia tenida con otros recursos similares, es posible establecer cuatro aspectos que deben ser considerados en cualquier estrategia para la industrialización de recursos similares:

-- Aprovechamiento integral del recurso.

-- Integración vertical a través del desarrollo de productos de mayor valor agregado.

-- Incremento de las densidades o número de plantas por Ha del recurso.

-- Investigación y desarrollo.

En la medida en la que estos factores puedan ser incluidos positivamente en los planteamientos para la explotación de esta tipo de recursos, mayores serán las posibilidades de contar con sistemas agroindustriales eficientes que permitan explotar adecuadamente nuestros recursos naturales renovables y se conviertan en verdaderos polos de un desarrollo económico y social sostenido en las regiones áridas y semiáridas de nuestro país.

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Summary.--The Creosotebrush (Larrea tridentata) is a resource of great abundance in arid and semi arid lands of Mexico. This report presents some general outlines of this resource and the different potential uses of it. We also present two industrialization options that are being studied at the Centro de Investigación en Quimica Aplicada (CIQA), as well as the results and conclusions to this report.

Aprovechamiento Industrializacion y Comercializacion de las Palmas "Corriente," "Del Istmo," y "De Chilapa" en el Desarrollo de las Comunidades Indigenas de la Region de la Mixteca[1]

Lic. Octavio Garcia Rocha[2]

Resumen.--La empresa de Participación Estatal Fidepal, S. de R. L. de I.P. y C.V., fue creada por Decreto Presidencial en 1973, con el fin de mejorar las condiciones sociales y económicas de la población que habita en la región de las Mixtecas en los estados de Oaxaca, Puebla y Guerrero, y la Meseta Tarasca en el estado de Michoacán. En el seno de este organismo se crearon los primeros Comités de la Palma, organizaciones de tejedores y recolectores de esta fibra natural que constituyen la base para la creación de Sociedades de Solidaridad Social para la industrialización y comercialización de las artesanias de palma, mismas que ahora integran Fidepal y sus unidades pe Producción.

GÉNEROS Y ESPECIES DE LA PALMA

En México existen dieciocho géneros de palmas nativas que agrupan sesenta especies. Siete géneros comprenden palmas de hoja en forma de abanico, mientras que las once restantes se caracterizan por contar con hojas que semejan una pluma.

Las palmas por lo general se localizan en regiones de clima tropical y subtropical. Sus particularidades más sobre salientes son su tallo simple y cilíndrico que puede ser liso, áspero o espinoso. En su parte inferior cuentan con raíces fibrosas y en la superior poseen un penacho de hojas., además de que sus flores son pequeñas, poco vistosas y sus frutos son variados.

Algunas especies son de importancia económica por sus variadas aplicaciones. Por ejemplo, los habitantes de las costas utilizan el tallo para la construcción de las armazones de sus chozas y las hojas para el techo de las mismas. En otros casos, el jugo del tallo contiene cierto tipo de azúcares que por el proceso de fermentación se convierte en una bebida alcohólica. Los frutos de algunas variedades como las de la "Palma de Coco", "Palma de Corozo", "Palma de Coyol Real" son comestibles, además de que bajo ciertos procesos se obtienen aceites de uso industrial. Mediante la utilización del cogollo de la "Palma de sombrero", de la real y de Jipi" se elaboran diferentes clases de sombreros, cestos, petates, cordeles, cintas, telas, etc.

Las palmas utilizadas en el tejido del sombrero pertenecen a la familia de las Palmaceas y se agrupan en los géneros Brahea, Sabal y Carludovica. Para el tejido, indistintamente en los tres géneros, solo se emplea el "Cogollo" o yema foliar de la planta.

Género Brahea

El Género Brahea agrupa las especies Calcarea, Conzatti, Berlandieri, Decumbes y Dulcis siendo esta última la única que se emplea para la manufactura del sombrero.

La Brahea Dulcis se caracteriza por contar con un tronco ó estipe que alcanza hasta más de diez metros de altura, sus peciolos dentados en los bordes miden hasta sesenta centímetros de largo y se encuentran cubiertos con una especie de lana fina de color blanco que se extiende hasta los limbos de las hojas tiernas y a las inflorecencias. Los limbos de las hojas son palmados es decir, en forma de abanico circular y miden hasta ochenta centímetros de largo, las flores de color blanco apenas alcanzan los dos milímetros de extension mientras que el fruto es ovalado de aproximadamente nueve milímetros de largo, de color verde cuando tierno y café negruzco al madurar. Esta especie de palma generalmente se desarrolla en altitudes que varían de 600 a 2 200 metros sobre el nivel del mar y se localiza en regiones de los estados de Oaxaca, Guerrero, Puebla, Veracruz, Morelos, Hidalgo, Queretaro y San Luis Potosí.

En la región Mixteca de Oaxaca existen palmares de esta especie en los poblados de Huajuapan, Nochixtlán y Silacayoapan, así como en la parte norte del distrito de Coixtlahuaca y sur de los distritos de Tlaxiaco y Nochixtlán. Los palma res cercanos a los centros urbanos o rurales de esa región presentan características de sobre explotación a tal grado que excepcionalmente alcanzan los seis metros de altura, sus "cogollos" son pequeños y de mala calidad. Esto ha propiciado que los campesinos tejedores la denominen "Palma Corriente" o "Anicera" y que sus cogollos de coloración verdosa se utilicen en la manufactura de los sombreros corrientes o "Aniceros", así como también en la elaboración de petates, mecates y colotes. Los bosques de palma existentes en las partes sur de los distritos de Silacayoapan, Tlaxiaco y Nochixtlán alejados de los centros urbanos y rurales han sido poco explotados. El cogollo de estos lugares es el mejor cotizado y por lo general se le conoce como "Palma Fina".

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[1] Ponencia presentada en la Reunión Sobre Manejo de Plantas en Zonas Aridas. Saltillo, Coahuila, México. Febrero 18-22, 1985.

[2] Octavio García Rocha, FIDEPAL, Sociedad de Recursos Limitado de Inversion Publica y Capital Variable.

Es conveniente mencionar, que a la especie Brahea Dulcis se le conoce con diferentes nombres vulgares, tales como Palma Corriente o Anicera, Palma Fina, Palma Blanca, Palma Jaltepec, Palma de Sombrero, Palma de Yosondúa o Palma de Silacayoapan. En los bosques de palma del municipio de Santiago Tilantongo, Oax., la Brahea Dulcis se mexcla con las especies Brahea Calcarea y Brahea Conzatti. A estas dos últimas se les conoce con el nombre vulgar de palma ceniza y plama de agua respectivamente, pero son escasas y por lo general se emplean para la elaboración de escobas.

Género Sabal

Este género agrupa veintiseis especies de las cuales en México solo se localizan las denominadas Duguesii, Mayárum, Yapa, Yucatánica, Uresana, Rosei, Texana y Mexicana, siendo esta última la que se utiliza en la manufactura de sombrero.

La Sabal-Mexicana se caracteriza por contar con un tronco o estipe que alcanza hasta veinte metros de altura, sus peciolos son lisos y miden alrededor de un metro, los limbos son costal-palmados, es decir, en forma de abanico curvados hacia abajo y miden alrededor de un metro. Las flores son casi blancas y miden de tres a cuatro milímetros de largo, mientras que el fruto de color café obscuro al madurar alcanza de quince a veinte milímetros de diametro.

Esta especie de desarrolla en las regiones tropicales contiguas a los litorales del Golfo y del Pacífico, en alturas no mayores de 500 metros sobre el nivel del mar, abarcando la planicie costera de Tamaulipas y regiones de los estados de Veracrúz, Oaxaca, Chiapas, Yucatán, San Luis Potosi, Jalisco, Colima, Michoacán y Guerrero.

Las mayores concentraciones de esta especie comunmente conocida con el nombre de "Palma Real", se localizan en la costa de Oaxaca entre puerto escondido y Chacahua, esí como en la región del Istomo de Tehuantepec. Con el material procedente de sus cogollos que alcanzan hasta 1.20 metros de largo y mediante diferentes técnicas se elaboran varios tipos de sombrero. Destacan los conocidos como "Campechanos" tejidos a mano por habitantes de la Mixteca Alta, para lo cual los tejedores adquieren los cogollos transportados desde la costa del Estado de Oaxaca, pero principalmente de la región conocida como Istmo de Tehuantepec. En esta región, particularmente en los lugares aledaños a la costa del distrito de Juchitán (Unión Hidalgo, Chicapa de Castro y Chahuites) los compesinos cortan el cogollo cerrado, lo rajan y lo asolean durante tres días para que se decolore hasta quedar casi blanco. Posteriormente hacen manojos de cogollos para su venta, o bien tejen largas tiras que llaman cintillas, que miden ocho brazadas de largo por tres contímetros de ancho y están integrados por grupos de tres o de siete palmillas.

Esta cintilla se cose a máquina dándole la forma de una especie de cono el cual posteriormente se plancha en una horma especial que le da la forma del sombrero conocido como del Istomo. Con una mecánica similar se elaboran diferentes tipos de bolsas, esteras, abanicos, cestos, carpetas, portafolios, capazos, etc.

Género Carludovica

De esta especie destaca la denominada Palmata que se cultiva y esplota principalmente en la localidad de Bacal en el Estado de Campeche, para manufacturar los sombreros finos conocidos como Jipijapa.

PROBLEMÁTICA ECONÓMICA Y SOCIAL

La región Mexteca sobre la que Fidepal enfoca sus principales acciones, abarca una superficie de 40 000 Km2, comprendiendo la parte noroccidental de Estado de Oaxaca y áreas meno extensas de los estados de Puebla y Guerrero.

La población de la región Mixteca según el censo de 1980 era de 622 mil habitantes, de los cualos el 72.3% (450 mil) se ubican en el Estado de Oaxaca y el restante 27.7% (172 mil) habitan en distintas proporciones los estados de Puebla y Guerrero.

La región presenta un relieve sumamente abrupto, su clima es simicálido y subhumedo, tiene suelos calcáreos, lluvjas irregulares y observa fenomenos de una ecología en deterioro. Las áreas ganaderas, parte de la superficie agrícola de temporal y las tierras improductivas, observan fuertes procesos de erosión; El 80% de la supervicie física de la región está en agudo proceso de destrucción.

La economía de los habitantes de la región Mixteca se complementa de manera importante mediante los ingresos que les reditúa el tejido de la plama, actividad que por lo general desarrolla la totalidad de los integrantes del núcleo familiar.

La palma se explota en una superficie de 83,950 has; generando unos 300 mil jornales anuales mediante la elaboracion de sombreros y otras artesanías. La presencia de acaparadores e intermediarios que compraban a precios sumamente bajos las artesanías de palma, menguando el ingreso de los tejedores, determinó la aparición de Fidepal, tanto para substraer a las comunidades indígenas de ese sometimiento económico, como para generar mayor volúmen de empleo mejor remunerado y propiciar la industrialización de los productos de palma en su región de origen.

Intermediarismo y Explotación al Recolector y Tejedor de Palma

El constante incremento en los niveles de producción de artesanías de palma, principalmente de sombrero en grena, ha contribuido a considerar la región de la Mixteca, como la principal fuente de abastecimiento de estos productos a nivel nacional.

La producción de artículos de palma distingue dos procesos, por una parte la extracción de la palma en su estado natural y por otra el tejido de sombrero y de otros productos similares.

La extracción de la palma comprende actividades de recolección, secado y clasificación. La recolección se efectua durante todo el año aunque se realiza en forma más intensiva en la época de secas, ya que la lluvia puede mancharla, demeritando su calidad y su precio. La actividad de secado se realiza al aire libre durante tres días y posteriormente se procede a su clasificación.

Es al término de este primer proceso donde se iniciaba la cadena de explotación, ya que el campesino productor realizaba la venta de su palma, en condiciones destavorables, a un grupo de intermediarios que acaparaban la totalidad de su producción.

Los intermediarios revendían la palma en los mercados de consumo de la propia región Mixteca, llegando a cotizarse precios hasta tres veces superiores a como la habían adquirido originalmente, lo que les redituaba grandes ganancias.

En la región Mixteca el tejedor de palma pone a la venta sus productos aprovechando los días preestablecidos de mercado. En ellos el intermediario procura adquirirlos al precio más bajo posible. También efectúan la venta de sus productos de palma a pequeños comerciantes de sus comunidades, quienes llegaban a acaparar a nivel regional gran parte de la producción. Cabe mencionar que esta relación comercial se regula generalmente a través del trueque, y en el intercambio el compesino tejedor de palma resultaba perjudicado.

El surgimiento de Fidepal, S. de R.L. de I.P. y C. V., en 1973 modificó en cierta manera esta realidad, aunque en el lapso hasta 1983 su importancia como comprador fué mínima. Sin embargo, en 1984 se adoptaron las medidas necesarias, para reactivar la compra y producción de artesanías de palma, de tal forma que de 28 mil unidades de artesanías de palma que se venían adquiriendo mensualmente a los camposinos, se aumento a 670 mil unidades mensuales, es decir, casi ocho millones de piezas de artesanía de palma durante 1984.

Ingreso y Empleo

Los habitantes de la región Mixteca desarrollan como principal actividad económica la relacionada con labores agrícolas, la cual se ha carracterizado tradicionalmente por su baja productividad debido, entre otros factores, a problemas en la tenencia de la tierra, erosión acelerada del suelo, escaso régimen pluviométrico, monocultivo, minifundismo, etc.

De la población total que se dedica a esta actividad se estima que el 60.0% obtiene ingresos aproximados de 15 mil pesos mensuales, cantidad que representa el 74% del salario mínimo promedio aprebado para la región.

El campesino mixteco ha encentrado en la recolección y tejido de la palma una manera de allegarse importantes ingresos adicionales a su mermada economía familiar. Fidepal en 1984 apoyó a esos grupos marginados mediante la compra de palma y de sus artesanías generando 160,000 jornadas de empleos indirectos al mes.

Adicionalmente, Fidepal brinda empleo directo a 507 trabajadores en sus cinco Unidades industriales que se ubican en la Región Mixteca (Puebla, Guerrero y Oaxaca) y la Meseta Tarasca de Michoacán.

Del total de estos trabajadores, 341 (76.5%) se clasifican como obreros y perciben el salario mínimo autorizado para cada región, es decir, un promedio de $820.00 pesos diarios. El resto de trabajadores 105 (23.5%) comprenden fefes de líneas de producción y recolección, mandos intermedios, personal administrativo y gerente general, quienes perciben ingresos superiores al salario mínimo teniendo como frontera los $130,000.00 pesos mensuales.

La Palma Como Insumo

Las cinco Unidades de Producción Industrial que integran a Fidepal, utilizan como insumo básico lo que se ha dado en denominar artesanías de palma, esto es sombrero en greña, cinta, tela, trenza, etc., cuyas particularidades, diferencias y utilidad las define la calidad de la palma (cogollo) y la técnica que se adopte en su tejido.

La trenza de palma tejida en los estados de Guerrero y Michoacán se utiliza para la fabricación de diferentes modelos de sombreros denominados "Finos" de gran demanda en el mercado nacional y del exterior.

La cinta y la tela de palma son materia prima para la elaboración de bolsas para dama, y bolsas para el mercado, mientras que el sombrero en greña, mediante ciertos procesos de acabado, es de utilidad para la fabricación de sombreros y portamaceteros, producto que tiene como destino principal el mercado de los Estados Unidos de Norteamérica.

Otros productos que elabora Fidepal teniendo como base la artesanía de palma son cestos roperos, manteles individuales, portapapelero, tortilleros, colchones playeros, portafolios, carpetas, capazos, porta vasos, sombrero para niño, sombrero para dama, tatamis, etc.

Las Unidades de Producción acorde con los fines para los que fueron creadas, no solo realizan labores propias de transformación e industrialización sino que colateralmente efectuan actividades de recolección, distribución y compra de artesanías de palma. Su acción contribuye a que los campesinos recolectores y tejedores obtengan mayores precios de garantía por sus productos.

ORGANIZACIÓN SOCIAL PARA SU APROVECHAMIENTO

Comités de la Palma

Los Comites de la Palma constituyen las organizaciones de los recolectores de palma y de los tejedores de artesanías en cada una de las localidades que atiende Fidepal en las Mixtecas de Oaxaca, Puebla y Guerrero.

El comité representa a los tejedores y recolectores de palma de una comunidad. Generalmente está integrado por un Presidente, un Secretario, un Tesorero y tres Vocales que son renovados cada año. En una comunidad de recolectores, el comité se encarga de pagar por la palma que entregan los campesinos recolectores a los precios de garantía vigentes. Para ello, Fidepal deja un fondo en el comité, recoge semanal o quincenalmente la materia prima. Si se trata de una comunidad de tejedores, entonces el comité no sólo se encarga de comprarle a sus socios las artesanías tejidas, sino también de proveerles de la palma necesaria y de administrar el dinero como fondo revolvente.

En la actualidad Fidepal opera con 208 comités de la palma, de los cuales 159 corresponden a localidades ubicadas en la Mixteca de Oaxaca.

Los comités de la palma son organizaciones representativas de la comunidad en la medida en que sus cuerpos directivos han sido olegidos democraticamente en asambleas de tejedores y recolectores de palma. Y justamente en esas poblaciones la recolección y tejido de la palma constituye la más importante actividad económica, cuando no la unica.

La organización y funcionamiento de los comités de la palma constituyen una vertiente de concertación con el sector social, donde Fidepal aporta posibilidades de empleo e ingreso al llevarles trabajo organizado a los tejedores de la palma hasta sus comunidades.

CONTRIBUCIÓN DE FIDEPAL A LOS OBJETIVOS SECTORIALES DE LA ESTRATEGIA ECONOMICA Y SOCIAL DEL ESTADO

La acción de Fidepal se encuentra dentro de la política sectorial del Estado en materia de Bosques, Selvas y Zonas Aridas, así como de Desarrollo Rural Integral. Actualmente Fidepal esta integrado por el Gobierno Federal, seis Sociedades de Solidaridad Social y 208 Comités de la Palma.

Sus principales objetivos son los siguientes:

(1) Coadyuvar en la elaboracion del nivel de vida de las poblaciones marginadas que viven del aprovechamiento de los bosques de palma.

(2) Generar empleo e incrementar el ingreso de los campesinos recolectores y tejedores de palma, apoyando su trabajo organizado, proporcionandoles financiamiento e interviniendo directamente en la transformación industrial de las artesanías de palma y en su comercialización, a fin de retener para la región el excedente económico generado.

(3) Eliminar a los intermediarios y acaparadores en este ramo, fijando precios de garantía que cada vez sean más remunerativos del trabajo artesanal.

(4) Proporcionar asesoría técnica a las empresas de ejidatarios, comuneros y cooperativistas en el cultivo, preservación, aprovechamiento, industrialización y comercialización de la palma.

(5) Promover en los Institutos Tecnológicos y Centros de Investigación, el estudio de procesos que optimicen el aprovechamiento del recurso, que aseguren la preservación y fomento de los bosques de palma y que capaciten a los compesinos en la operación y administración de su actividad.

(6) Finalmente, coadyuvar al equilibrio de la balanza comercial mediante la exportación de artesanías de palma con alto porcentaje de mano de obra en su valor agregado.

Summary.--The inter-state organization known as FIDEPAL (trusteeship for the enhancement and development of palms and their products) was formed by a Presidential Decree in 1973. It was founded to enhance the social and economic conditions of the population of the "Mixtecas" region in the states of Oaxaca, Puebla and Guerrero, as well as the "Meseta Tarasca" in the state of Michoacán. Within the organization, the first palm committees were created--organizations of weavers and collectors of this natural fiber for the industrialization and commercialization of palm handicrafts, which currently integrate FIDEPAL and its production units.

La Calabacilla Loca (*Curcurbita foetidissima*), un Recurso con Potencial en las Zonas Aridas[1]

José Luz Chávez Araujo[2]

Resume.--La Calabacilla loco Cucurbita foetidissima (HBK), especie nativa de zonas áridas posee las siguientes características: semillas ricas en aceite y proteínas y alto contenido de almidón en su raíz. Características que situan a esta especie como un nuevo cultivo agrícola en estas regiones una vez domesticada.

INTRODUCCION

Es por todos conocido que las zonas áridas y semiáridas de México, así como de otras partes del mundo por sus características climatológicas y edáficas de estas regiones, no es posible utilizar grandes extensiones de tierra para la siembra de cultivos alimenticios; sin embargo, éstas poseen dentro de su flora un gran número de especies silvestres que pueden aprovecharse como fuente alimenticia o industrial, las cuales a la fecha no han sido objeto de investigaciones propias para su aprovechamiento.

Una de estas especies es la Calabacilla loca, especie silvestre y perenne que se encuentra creciendo naturalmente en estas regiones, cuyas semillas son ricas en aceite y proteínas, posee además un alto contenido de almidón en su raíz, así como un alto contenido de follaje el cual puede ser utilizado como forraje. Estas características hacen de esta planta una posible fuente de alimentos o de productos industrializables, por lo que se situa como un cultivo de futuro.

La Calabacilla loca ha sido estudiada por diversos investigadores quienes la consideran como un cultivo de amplio potencial agroindustrial, tales como los realizados por Curtis en 1946 quien reporta 33% de aceite y un 43% de proteína en sus semillas. De la información de Bemis et al. (1975, 1978), Berry et al. (1976) y la generada por UAAAN (1974-1984), se considera que la Calabacilla loca tiene el potencial necesario para valuarla como un cultivo alimenticio por sus características que posee.

La importancia de la Calabacilla loca estriba principalmente en el contenido de aceite y proteína de la semilla y almidón de la raíz. El contenido de aceite y proteína varía de 25.6 a 42.8 y 22.2 a 32.1%, respectivamente y de 50-60% de almidón en base a peso seco de las raíces (Curtis, 1972 y Barry, 1974). La importancia económica del aceite y proteína es vital en el presente, debido a que existe un fuerte déficit de alimentos nutritivos y aceites comestibles en nuestro país, lo cual hace necesario maximizar la eficiencia en aquellos cultivos en explotación y a la vez incorporar a la producción todos aquellos con potencial alimenticio e industrial.

CARACTERISTICAS GENERALES DE LA PLANTA

La Calabacilla loca Cucurbita foetidissima (HBK) se le conoce también con los nombres comunes de "Calabacilla", "Calabaza Bufalo", Chilicayote", "Calabacilla Amarga o Apestosa" y otros más (Stevenson 1948, Bemis y Whitaker, 1969).

La Calabacilla loca es una planta perenne, herbacea, tosca y aspera al tacto, crece durante los meses de abril a octubre (en México), posee numerosos tallos (guías) rastreros de 4-6 m de longitud cuando las condiciones son propicias; éstos son débiles, delgados y escabrosos; nacen de una raíz principal extendiéndose a todos los lados en forma circular; la mayoría de ellos produccen ramificaciones secundarias las cuales también producen frutos.

La raíz principal es de considerable tamaño por lo que posee gran capacidad de almacenamiento de reservas. El peso de esta raíz es variable, habiéndose reportado pesos frescos de: 72 a 45 kg para raíces de 3 años de crecimiento, sin embargo lo más comunmente encontrado son raíces de 4-6 kg en dos años de crecimiento.

La reproducción de la Calabacilla loca en estado silvestre es principalmente asexual, ya que en cada nudo de las guías puede desarrollarse una raíz adventicia que da origen a una nueva planta, formandose de esta manera densas colonias de plantas en lugares con captación de agua a través de escurrimientos naturales, o en regiones donde las lluvias son regulares.

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[1] Ponencia presentada en la Reunión Sobre Manejo de Plantas en Zonas Aridas. Saltillo, Coahuila, México. Febrero 18-22, 1985.

[2] Ing. Agr. M.C. Encargado del Programa sobre Domesticación de la Calabicilla loca. Depto. de Fitomejoramiento. División de Agronomía de la UAA"AN", Buenavista, Saltillo, Coahuila. México.

Los frutos son por lo general redondos y periformes de diferente tamaño (4-8 cm), son de color verde con franjas blancas con pulpa muy filamentosa y amarga de color blanca. La producción de frutos por planta es muy variable; las semillas son pequeñas; oblongas-ovaladas de aproximadamente 12 mm de largo y 6-7 mm de ancho. El número de semillas por fruto varia de 200 a 300 semillas por fruto, con un promedio de 4 gr de peso por 100 semillas.

La Calabacilla loca posee una amplia distribución en Norte américa desde el Oeste de los Estados Unidos hasta el Sur de Guanajuato; sin embargo, aunque su distribución dentro de la República Mexicana aún no ha sido completemente determinada, se puede encontrar en forma silvestre en practicamente cualquier lugar del árido mexicano y regiones similares, o sea que se encuentra en casi todo el país.

Esta planta generalmente se desarrolla en un amplio y variado tipo de suelos, prosperando mejor en suelos profundos arenosos, pedregosos de poca pendiente, de regular humedad y bajo diferentes agroclimas. Comunmente se encuentra en terrenos removidos (áreas de disturbio) como a la orilla de: caminos, vías férreas, carreteras, basureros, corrales de ganado, canales de riego o todo aquel lugar donde se encuentre material orgánico con regular humedad, desde prácticamente el nivel del mar hasta alturas mayores de 2,000 msnm. Así mismo cabe hacer notar que la Calabacilla loca se desarrolla satisfactoriamente en suelos con problemas de sales.

POTENCIAL ALIMENTICIO Y/O INDUSTRIAL

El contenído de aceite y proteína de la semilla de Calabacilla loca compite con el de otras oleaginosas, entre ellas: soya, algondón, girasol y ajonjolí, ya que únicamente es superada por la soya (37.9%) y ajonjolí (41.3%) en cuanto a proteína y aceite se refiere (Fig. 1).

Por otro lado, el aceite de la Calabacilla loca contiene 61% de ácido linoléico, componente principal de los aceites comestibles y ácido graso esencial en la dieta alimenticia tanto en humanos como en animales. A este respecto la Calabacilla loca es superada únicamente por el cártamo (75%), (Fig. 2).

Asimismo, los residuos de la semilla (harina) una vez extraídos el aceite muestran ser una harina de buena calidad en base a su proteína. Los aminoácidos de esta planta han sido comparados con los del huevo, los cuales (estos últimos) son ligeramente superiores a los de la Calabacilla loca; sin embargo, presentan grandes posibilidades para utilizarse como una fuente de proteínas al incluirse en dietas alimenticias de animales poligástricos (rumeantes: bovinos, ovinos, caprinos, etc.) y monogástricos (cerdos, aves, conejos, etc.).

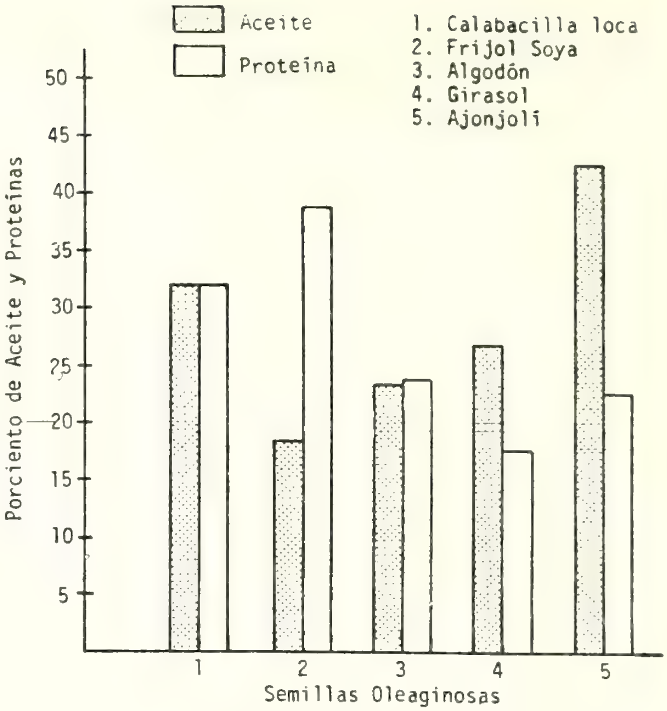

Fig. 1. Comparación de la semilla de Calabacilla loca con semilla de otras oleaginosas.

El almidón de la raíz puede ser hidrolizado por métodos enzimáticos y químicos para obtener dextrinas, maltosa y glucosa.

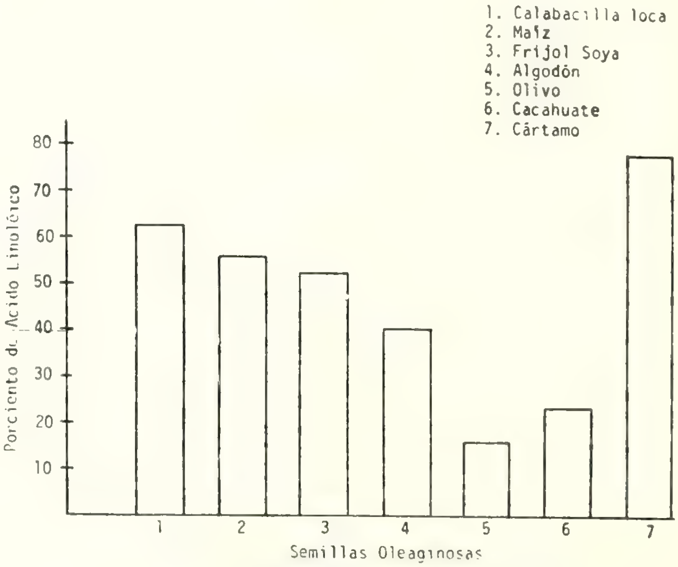

Fig. 2. Contenido de Acido Linoléico en Oleaginosas, comparado con el de la Calabacilla loca.

Cuadro 1. VOLUMEN DE SEMILLAS DE OLEAGINOSAS, GRASAS Y ACEITES VEGETALES IMPORTADOS POR MEXICO DURANTE 1972 Y 1978

PRODUCTO	1972		1978	
	TONS	$ (MILES)	TONS	$ (MILES)
Semillas	26,682	125,600	957,697	5'909,138
Grasas y Aceites Vegetales	25,547	156,177	141,922	1'910,038

FUENTE: Secretaría de Programación y Presupuesto 1980.

IMPORTANCIA ECONOMICA COMO CULTIVO

En México la demanda de aceites y grasas vegetales va en aumento, año con año, debido a la alta tasa de crecimiento de la población y a la baja producción de los mismos.

Según de la Garza (1978) México tiene que producir 20,000 ton más de aceite año con año para cubrir las necesidades de consumo. De ahí que nuestro país se vea en la necesidad de importar grandes cantidades no sólo de semillas oleaginosas sino de aceite mismo. Así tenemos que en 1972 México importó 26,682 ton de semillas, en 1978 las importaciones fueron de 957,697 ton y para 1981 se compraron 1.3 millones de ton. Es obvio por lo tanto, que nuestro país tenga fuertes fugas de divisas tan solo por este concepto (Cuadro 1).

Por lo anterior, la Calabacilla loca se vislumbra pues, como una posible alternativa para solucionar en parte la escasez que se tiene de aceites y de otros productos industrializables una vez que esta especie se incorpore como un nuevo cultivo agrícola.

Asimismo, la Calabacilla loca a parte de considerarse como una fuente de alimentos, puede ocupar superficies que actualmente no son utilizadas en forma alguna por otros cultivos tradicionales tales como: maíz, frijol, trigo y otros, ya que esta especie requiere de mínima humedad y de suelos no muy especializados para expresar su máxima producción (frutos y/o semilla) bajo condiciones no muy benignas en las cuales otros cultivos no prosperan.

Por lo tanto, es importante hacer notar que en vista del déficit de semillas oleaginosas y en base al potencial que a este respecto presenta la Calabacilla loca, será sin duda una portación valiosa que coadyuvará a resolver en parte el probleema de importación de aceites una vez que esta especie se incorpore como cultivo agroindustrial.

INVESTIGACIONES REALIZADAS

En base al potencial plenamente comprobado que posee la Calabacilla loca, la UAAAN conjuntamente con los organismos oficiales interesados en resolver en parte la situación que viven las zonas áridas y semiáridas de México inició en 1974 investigaciones tendientes a la domesticación de la Calabacilla loca para tratar de incorporarla como un nuevo cultivo oleaginoso.

Los estudios de domesticación se han llevado a cabo en los campos experimentales de: Matehuala, S.L.P., Cuencamé, Dgo., Navidad, N.L., Ocampo y Buenavista, Coah., localidades enclavadas dentro de las zonas áridas y semiáridas, pero de diferentes condiciones agroclimáticas.

Asimismo cabe hacer notar que para la domesticación de cualquier especie silvestre, se requiere de la participación de diferentes disciplinas para el conocimiento y manejo de la planta. En este renglón las investigaciones se han dirigido en básica y aplicada.

Por lo tanto, las investigaciones realizadas a la fecha en esta planta son las siguientes:

1. Colecta e introducción de materiales.
2. Pruebas de germinación de semillas (laboratorio, vivero e invernadero).
3. Pruebas de comportamiento de materiales nativos e introducidos.
4. Evaluación de materiales bajo riego y temporal.
5. Propagación vegetativa.
6. Evaluación de materiales sobresalientes.
7. Fecha óptima de cosecha.
8. Establecimiento de lotes semicomerciales para estimar: producción, costo e impacto socioeconómico.

Además de lo que a la fecha se ha generado, se esta investigando sobre cultivo de tejidos, reproducción asexual a través de partes vegetativas (guías) y la inducción de flores femeninas a través de fitoreguladores para incrementar la producción de frutos por planta y/o unidad de superficie.

Por consiguiente en base a la información generada por las investigaciones realizadas, a las observaciones y experiencias obtenidas en esta planta se ha llegado entre otras, a las siguientes conclusiones:

1. La calabacilla loca por su condición xerófita, rusticidad y tolerancia a condiciones adversas, muestra ser un cultivo de futuro para las zonas áridas, semiáridas y regiones similares.

2. La Calabacilla loca a pesar de ser una planta que bajo condiciones naturales se desarrolla satisfactoriamente, ésta una vez establecida bajo cultivo se vuelve susceptible al ataque de plagas y enfermedades, así como exigente de humedad.

3. Para el establecimiento de siembras comerciales es necesario tomar en cuenta la época en la que regularmente se presentan las lluvias para asegurar el establecimiento de las plantaciones.

4. La Calabacilla loca puede establecerse en un amplio y variado tipo de suelos; sin embargo, prospera mejor en suelos removidos con buen drenaje (suelos de disturbio) y suelos ricos en materia organica.

5. La domesticación de la Calabacilla loca coadyuvará en la economía y vida de los habitantes de las zonas áridas, lo que favorecerá un cambio social para un mejor nivel económico y cultural de sus habitantes.

Lo antes expuesto no quiere decir que a la fecha ya se haya investigado todo lo necesario como para lanzar a la Calabacilla loca como un nuevo cultivo; sin embargo, considerando su potecial tanto alimenticio como industrial para el futuro, es de vital importancia generar el paquete agronómico que permita explotar a esta planta a nivel comercial, para lo cual se requiere ampliar e intensificar las investigaciones agronómicas, industriales y nutricionales que aún no se han realizado exaustivamente. Por lo tanto se requiere del apoyo firme y decidido de las instituciones u organismos oficiales que buscan alternativas y/o soluciones ente la escasez de alimentos que cada día se agudiza.

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Summary.--The Buffalo gourd, Cucurbita foetidissima (HBK), a native species of arid lands, has seeds rich in oil and proteins, and a high starch content in its roots. Once it has been domesticated, this species may be cultivated as a new agricultural crop.

Arid Land Plant Research at the Caesar Kleberg Wildlife Research Institute[1]

Edward Glumac, Peter Felker, Yashpal Goyal, Sharon Klass,
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and Sonia de Souza[2]

The Caesar Kleberg Wildlife Research Institute was established at the College of Agriculture of Texas A&I University in 1981 with a grant of $3.3 million from the Caesar Kleberg Foundation for Wildlife Conservation to facilitate research aimed at enhancing the understanding of wildlife populations in the south Texas region. Better understanding of the wildlife habitat will lead to more productive management of local and exotic wildlife species.

Additional research is being conducted on several semi-arid and aridland plant species. These include mesquite (Prosopis spp.), Leucaena (Leucaena spp.), Cactus (Opuntia spp.), and saltbush (Atriplex spp.). A research priority of the Institute is the development of strategies to increase the economic returns to landowners from wildlife and their habitat. Within this context, the two primary goals of the aridland plant research group at Texas A&I are 1) to investigate the feasibility of establishing wood energy plantations in a semi-arid environment with Prosopis and Leucaena, and 2) production of animal fodder using Leucaena, Opuntia, and Atriplex species.

This paper will concern itself mainly with the production, management, and utilization of Prosopis and Leucaena species under non-irrigated and minimum fertilizer input conditions in annual rainfall zones of 450 and 760 mm.

RESEARCH TASKS

Tree legume research at Texas A&I University is divided into several areas. These are 1) tissue culture of clonal material 2) rooting of cuttings and 3) field trials of superior varieties.

Tissue culture research is deemed necessary to produce true to type genetic material for species such as Prosopis which are self-incompatible (Simpson, 1977). As a result of self-incompatibility, trees propagated from the seed of Prosopis have a high variability. Tissue culture also has the capability to produce a million plantlets per year from a single auxillary bud.

Research has concentrated on Prosopis alba clone B_2V_{50} which is a fast growing variety with few thorns. This clone was derived from a southern California P. alba ornamental accession (Felker et al, 1983) that had been one of the highest biomass producing accessions in a screening trial carried out at the University of California Riverside research plots. Although tissue culture of other Prosopis species has been carried out successfully (Goyal and Arya, 1984), P. alba has not yet been produced from bud explants. Leaves can be developed routinely from the explants. Leaves can be developed routinely from the explants, however, shoot development has been slow to develop for the B_2V_{50} clone. Work is progressing in this area trying to determine optimal levels of cytokinins and auxins, evaluate basal salt media, and determine effects of environmental parameters.

An experiment carried out in 1983 examined 8 concentrations of cytokinins and 5 concentrations of auxins (indoleacetic acid). Although some shoot development did occur, it was not statistically significant between levels of the 2 factors. Three different IAA/kinetin rations which produced shoots were selected for further study and the results showed that at the higher IAA concentrations leaf formation was reduced. Another experiment which examined two different cytokinins, benzylaminopurine (BAP) and kinetin showed no differences in leaf development between the two cytokinins.

There are currently 3 basal salt media which are widely used in plant tissue culture. Experiments have been conducted to test each of the 3 media at quarter, half, and full strength. These three media are Murashige-skoog, Gamborg B5, and "woody plant media." Results indicate that a greater response is obtained using full strength media and that the Murashige-skoog media appears to be the most promising. We believe that there may be a correlation between the amount of ammonium in the media and leaf development as the Murashige-skoog media has 1650 mg L^{-1} NH_4NO_3 as compared to 400 and 0 for the woody plant and Gamborg B5 media respectively. In addition, it now appears that larger explants have greater leaf development. This may indicate that a nutrient reservoir present in the explant, but not in the culture media is limiting explant development.

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[1] Paper presented at the Meeting on Management and Utilization of Arid Land Plants, Saltillo, Coahuila, Mexico, February 18-22, 1985.

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We decided to look at environmental factors such as light intensity and temperature because these have been shown to be important rooting of cuttings research. Earlier work had been done at ambient room temperature and at a light intensity of about 200 ft candles. Four different air temperatures of 25, 28, 31, and 34°C were investigated and light intensities of 450, 220, and 110 ft candles were used with one level of kinetin and IAA. The optimum combination from this experiment seems to be an air temperature of 28°C and 450 ft candle light intensity.

Tissue culture research has also centered on propagation of Leucaena leucocephala (K-67), one of the fastest growing varieties of this species. This plant has been relatively easy to propagate by tissue culture. Dr. Goyal has been able to routinely produce multiple shoots up to 7 cm long and has successfully dissected and subcultured portions of the multiple shoots (Goyal et al. 1985). With the proper nutrient/hormone combination about 95% of the node sections are induced to produce 2-3 shoots of about 4 cm average maximum length in 5 weeks. When the tissue culture medium is changed to a formulation high in auxins, roots are produced on 90% of the shoot sections. These rooted plantlets have been successfully transferred to a soil mixture and grown into seedling size plants.

As with tissue culture, rooting of cutting research is needed because of the obligate outcrossing nature of Prosopis. The first successful rooting of mesquite cuttings was reported in the Journal of Range Management (Felker and Clark, 1981). The technique used could produce 100% rooting of clone 0351 in the Spring but only 15% in November. Overall, about 70% rooting was obtained for 6 species having widely divergent origins (Felker and Clark, 1981).

A study was initiated in 1981 at Texas A&I to examine the influence of environmental parameters on the rooting of cuttings, specifically those of Prosopis alba clone B_2V_{50}. The environmental parameters looked at were photoperiod, light intensity, light quality, and temperature. These parameters were examined for the effect they had on percent rooting, maximum root length, and number of roots per cutting. We have found the optimum air temperature for rooting to be 35°C. Light intensities of greater than 520 uE m^{-2} sec^{-1} produced the greatest percent rooting, maximum root length, and number of roots per cutting.

The effect of length of photoperiods was examined to determine if there are differences that might affect the ability of cuttings to root. Four growth chambers were used to simulate photoperiods of 8, 12, 18, and 24 hours. The stockplants from which the cuttings were taken were also placed in the growth chambers. Cuttings from stockplants grown at each of the 4 photoperiods were examined at all 4 photoperiods for a total of 16 treatments. This allowed testing of stockplant by photoperiod interactions. Stockplants were moved to a new growth chamber every 3 weeks. This experiment was replicated 4 times. The statistical design of this experiment allowed for chamber and block effects to be examined, neither of which were significant ($P > 0.15$). The interactions between cutting and stock-plant photoperiod were also not significant. The best root development occurred at the 18-hr cutting photoperiods and the greatest average percentage rooting occurred at the 12-hr photoperiod, however these differences were not significant at $P = 0.05$.

As a result of knowing the optimal environmental parameters for rooting Prosopis alba B_2V_{50}, it was possible to achieve a rooting percentage of 83% during the period January-June of 1983 in a growth chamber. This work has been extended to a light bench in our greenhouse and rooting percentages of 75% has been achieved over a 6 month period.

FIELD TRIALS WITH PROSOPIS AND LEUCAENA

Field trials are being conducted on a 14 hectare site adjacent to the University, a 4 hectare site (Zachary Ranch) 160 km from Kingsville halfway between Hebbronville and Zapata, Texas and a 0.1 hectare site 10 km south of Kingsville. The Kingsville site have a annual rainfall of about 760 mm and the Zachary Ranch site about 450 mm. Prosopis is being evaluated under both rainfall regimes and Leucaena under the 760 mm regime. Management practices under investigation include screening trials, rotational cropping cycles, mineral nutrient requirements, and cultural-herbicide usage.

Prior to analyzing management techniques which will produce the highest yields, it is necessary to screen cultivars for selection of the highest yielding lines in a given geographic area. Initial work with Prosopis was carried out by Peter Felker at the University of California Riverside (Felker et al., 1982). A germplasm acquisition program was begun in 1978. About 150 Prosopis accessions were collected on a 3,000 mile field trip through the California desert. Another 300 came from a Peruvian collection maintained by Dr. Alva in Lima, Peru and Dr. Solbrig at Harvard University contributed 150. Other accessions were gathered from various sources in Hawaii, Argentina, Chile, Senegal, Sudan, South Africa, and the Carribean. This collection represents the largest germplasm pool of Prosopis in the world.

Within the last year, an IBM personal computer has been purchased to provide data management of this collection. All 1100 Prosopis accessions have been entered into a computerized filing system. This system allows for more efficient storage and retrieval of information as well as providing the capability to cross reference data entries according to individual characteristics.

A collection of over 75 Leucaena and 100 Cactus are also present as well as some Acacia and Pithecellobium accessions. This includes a rangewide collection of Leucaena pulverulenta made on a collection trip throughout south Texas in 1982.

A screening trial at Riverside, California in 1979 compared biomass production per tree for 51 accessions of Prosopis and 4 accessions 51 other tree legumes including Leucaena, Parkinsonia, Olneya, and Cercidium (Felker et al, 1983). Irrigation was used in this trial because of the low annual rainfall (65 mm/yr). Results of this trial showed a 160-190 fold range in means and a large range in variability within accessions. The Prosopis alba accessions were superior to all others in terms of dry biomass production. Clone B_2V_{50} was taken from a tree belonging to accession 0194. It is this clone which is under intensive investigation in south Texas.

There are currently 9 experimental plantings of Prosopis which are determining pod, biomass, and timber production (Wiesman et al., 1984). As Prosopis has never before been planted as a plantation crop, we have had to devise our own methods for transplanting and maintaining these trees on marginal soils. The first step in this process involves preparation of land that is covered with brush. The existing vegetation must first be cleared off the land and burned. A moldboard plow is used to turn over the soil. Several passes are then made with a disk cultivator and Roundup herbicide is applied to eliminate remaining vegetation.

We have evaluated several herbicides for use in maintaining weed control in the Propsopis and Leucaena plantings and have eliminated some as being phytotoxic to the trees. One of these that is worth mentioning is the herbicide bromacil (Hyvar). This herbicide was applied to a Prosopis clonal plot which had been established in April of 1982 and to which bromacil had been applied in September of 1982 at the rate of 1.5 kg ha^{-1} and 3.0 kg ha^{-1} the following February. Phytotoxic symptoms were not observed until 5 months after the second application and by November of 1983 these plots had suffered irreversible damage.

We have also investigated the pre-emergence herbicides oxyfluorfen (Goal), oryzalin (Surflan), alachlor (Lasso), metolachlor (Dual), and napropamide (Devrinol) at two different rates for use in transplanting L. leucocephala (K-67) and P. alba (Felker et al., 1984). Percent weed cover was evaluated at 45, 75, and 105 days after planting and basal diameters of all trees were measured 110 days after transplanting. Existing regression equations were used to convert basal diameters to dry weights. The greatest dry biomass per tree was achieved with Oryzalin at a rate of 2.8 kg a.i. ha^{-1} (2X). Oryzalin also provided the best combination of grass and forb control. We feel that some kind of weed control is necessary when trying to establish leguminous trees in semi-arid conditions because of the competition with grasses and forbs for available moisture. This control could be maintained with herbicides in combination with mechanical cultivation at costs which would be reasonable especially if carried out on larger scale plantations. Costs for oryzaline at the 2X rate on a per hectare basis in 1981 dollars were $77 (Felker et al., 1984). This cost could be reduced using oryzalin at the 1X rate in combination with mechanical cultivation. A leaf second herbicide trial was established in 1984 to compare weed control and phytotoxic effects of inexpensive long residual herbicides for use on trees that have already been established. Herbicides that are being tested include Dachthal, HyVar, Krovar, Karmex, Solicam, and Simazine at two rates of application. The 4 ha plot at Zachary Ranch was established because it is in a region that has only 450 mm rainfall, about 300 mm less than Kingsville. The mean daily July maximum temperature is 38°C whereas Kingsville is 36°C. Survival rates of the 3 clones and 1 seed propagated accession established in 1983 ranged from 86.7-99.7% and the dry biomass per hectare ranged from 1,440 kg ha^{-1} to 3,560 kg ha^{-1} 9 months after planting. These trees were planted on a 3m x 3m spacing. An electric fence has been constructed around these plots to protect the coppice regrowth from the abundant deer population in the area.

We have compared two different types of containers for use in transplanting seedlings to the field. One container is a 3.8 cm x 3.8 cm x 38 cm cardboard container that is open at the bottom and is left on the seedling when transplanted to the field. The other container is a 20 cm plastic dibble tube which is removed just prior to planting in the field. Survival percentage and dry biomass are different for Prosopis and Leucaena. The cardboard plant bands which are left on the seedling gave higher rates of survival for both Prosopis and Leucaena, however the dry biomass per tree was higher in the Leucaena using the plastic dibble tubes and no significant difference was observed for Prosopis. This difference may be due to a difference in root systems. Prosopis has a root which goes down straight for water as opposed to the roots of Leucaena seedlings which are more fibrous and may be constricted in the cardboard containers.

Leucaena is being tested at our Kingsville plots for production as a woodfuel source and for animal fodder. Leucaena has been distributed worldwide for use as woodfuel, animal forage, reforestation, soil improvement, and as a source of protein (NAS, 1984). It grows best in areas receiving from 1000-3000 mm of rainfall per year, although it is tolerant of droughts and can survive in some areas receiving as little as 250 mm rain (NAS, 1984). The soil on which Leucaena grows seems to be important for high rates of productivity. It has been stated that Leucaena has the capability to grow and break up impervious soils (Dijkman, 1950), however our experience is that certain soil types can greatly reduce productivity. We have 2 soil types on which Leucaena is growing. The Orelia series soil is underlain at 15 cm by a natural hardpan which appears to be restricting root penetration or water movement whereas an adjacent Willacy series soil lacking the hardpan is moderately permeable to a 60 cm depth. Yields of L. leucocephala (K-8) on the Willacy soil (8,000 kg ha^{-1}) have been 4 times those on adjacent Orelia hardpan soil (2,000 kg ha^{-1}). We are attempting to correlate plant tissue analysis and physical properties with biomass yields for the particular experiment.

A screening trial was established in March of 1983 to compare 65 accessions of Leucaena, 37 L. pulverulenta, 25 L. leucocephala, and 1 L. retusa. A randomized complete block design was used consisting of 5 trees of each accession in 4 blocks for a total of 20 trees per accession. Survival percentages and growth rates are being monitored to select for the highest biomass yielding accessions. The highest yielding trees are L. leucocephala accessions, especially the K varieties developed at the University of Hawaii by Dr. Brewbaker (K-8 and K-67). We also have several other non-selected leucocephala varieties that show potential for the south Texas region.

The unselected L. pulverulenta accessions, although not as fast growing as the K-varieties appear to have some advantage in ability to tolerate mild freezing temperatures. A freeze in the first week of December 1984 saw the temperature fall to -4.5°C and 10 hr of below freezing temperatures were recorded. Most of the leucocephala varieties were injured as evident by the almost total loss of leaves, whereas the pulverulenta accessions showed only very slight signs of injury.

A record breaking freeze in December 1983 which sent temperatures plummeting to -12°C killed all accessions with the exception of L. retusa which was completely undamaged. This freeze had a probability of occurring about once in 125 years (LeHouerou, 1984). The potential exists for transferring the cold tolerance of L. retusa to the more prolific varieties of L. leucocephala or L. pulverulenta (Brewbaker, 1984) by making selected crosses of these species.

A promising use for Leucaena in semi-arid conditions is for forage production, either in a livestock grazing system or for mechanical harvesting and processing systems. We have purchased a John Deere Model 25 ensilage cutter and our initial experience is that large quantities can be easily cut using this equipment. We are investigating ways to process the cut material, by drying, ensiling, or pelletizing.

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RESUMEN

A partir de 1981, el Caesar Kleberg Wildlife Research Institute de la Universidad de Texas A&I ha efectuado investigaciones sobre especies de tierras aridas y semiaridas tales como Prosopis, Leucaena, Opuntia y Atriplex. Los objectivos a largo plazo son los de obtener benficios economicos para los rancheros de la region del sur de Texas.

Se han usado tecnicas de cultivo de tejidos para propagar y multiplicar Prosopis debido a la alta variabilidad en la progenie propagada a traves de semillas. Experimentos en condiciones de laboratorio han sido efectuados para determinar los niveles optimos de auxinas, citoquininas y nutrientes para facilitar el desarrollo de los brotes y de las raices en el material vegetal de clon. Leucaena leucocephala (K-67) ha sido exitosamente propagada de esta manera.

La investigacion sobre el enraizamiento de los fragementos clonales se ha centrado sobre Prosopis clon B_2V_{50}. Varios parametros ambientales que afectan la capacidad de enraizamiento de los fragmentos, tales como temperatura, fotoperiodo y la intensidad de la luz, estan siendo investigados para maximizar el enraizamiento.

Variedades superiores de Prosopis y Leucaena han sido probadas en condiciones naturales bajo dos regimenes pluviales. Prosopis ha sido evaluado en regimenes pluviales de 760 y 450 mm annuales y Leucaena en una area con 760 mm de lluvia anual. Herbicidas preemergentes y de post-estableciemento se han evaluado para controlar la competencia con malezas por humedad, un factor critico en condiciones de aridez o semi-aridez.

Se han investigado el potencial en tres especies de Leucaena para producir una biomasa de madera o farraje en una area que es sujeto de frecuentes heladas. El tipo de suelo en el cual Leucaena crece es aparentemente un factor limitante para una alta productividad.

Patton, David R.; Gonzales, Carlos E.; Medina, Alvin L.; Segura, Luis A.; Hamre, R. H., tech. coords. Management and utilization of arid land plants: symposium proceedings; 1985 February 18-22; Saltillo, Mexico. Gen. Tech. Rep. RM-135. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1986. 113p.

These proceedings contain 19 papers presented as part of a continuing cooperative effort in forestry and related resources between Mexico and the U.S. Primary species discussed include jojoba, guayule, palms, prickly pear, candelilla, mesquite, buffalo gourd, creosotebush, Indian ricegrass, and yerba del manso. Papers are in the language of the author (Spanish or English) with an abstract in the other language.

Keywords: Arid land plants, desert agriculture

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Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

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Research Natural Areas in New Mexico

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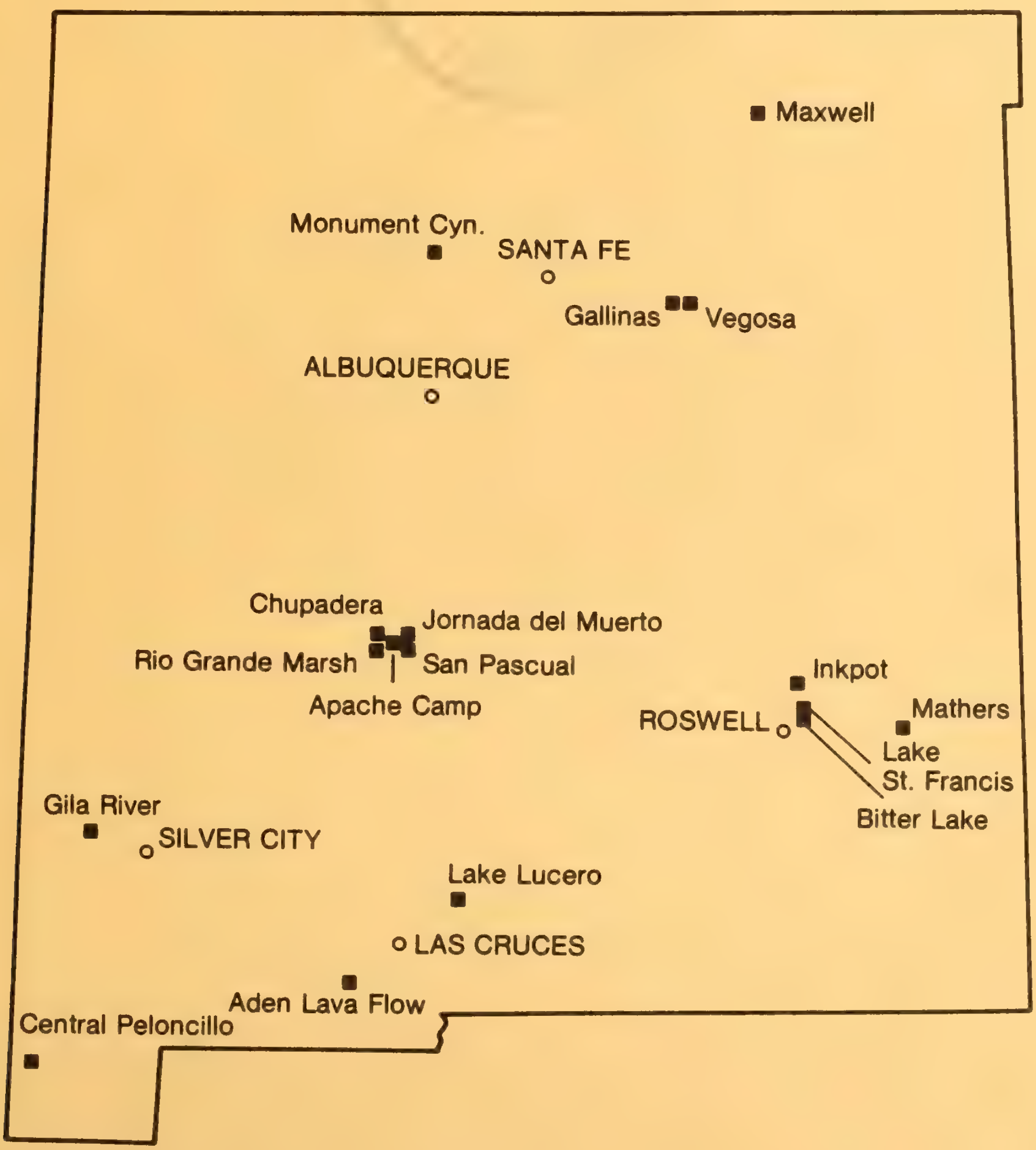

Abstract

New Mexico's 17 Research Natural Areas are described. Included are maps, photographs, and brief accounts of administration, climate, physiography, geology, soils, vegetation, fauna, research uses, and references. Threats and intrusions are noted. This information should be useful to scientists interested in conducting botanical or zoological research in New Mexico.

Acknowledgments

Patient responders to questions in the USDI Fish and Wildlife Service, Bureau of Land Management, National Park Service, and the USDA Soil Conservation Service made this report possible.

Photographs of four areas were provided by Jerry M. Hoffer (University of Texas—El Paso), John C. Egbert (The Nature Conservancy, Albuquerque), Loren D. Potter (University of New Mexico), and Robert J. Schumerth (White Sands National Monument).

USDA Forest Service
General Technical Report RM-136

October 1986

Research Natural Areas in New Mexico

Roger S. Peterson, Secretary

and

Eric Rasmussen, Technical Assistant
New Mexico Natural History Institute
Santa Fe, New Mexico

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Research Natural Areas in New Mexico

Roger S. Peterson and Eric Rasmussen

INTRODUCTION

"Research Natural Area" (RNA) is a land management category used by federal agencies since 1927 to designate lands permanently reserved for research and educational purposes. Natural processes are supposed to dominate in these tracts, which preserve some natural features. Principal goals in protecting these lands are:

1. To preserve a representative array of all significant natural ecosystems as sources of baseline data, against which the effects of human activities in similar environments can be measured.
2. To provide sites for studies of natural processes in undisturbed ecosystems.
3. To provide gene pool preserves for plant and animal species, especially rare ones.

In 1977, 4.4 million acres in 46 states and one territory were included in the 389 RNA's in the United States.

Other management categories on federal lands in New Mexico that share some attributes with RNA's are "outstanding natural area," "area of critical environmental concern," "wilderness," "critical wildlife habitat area," "national environmental research park," and "experimental ranch." Even without such titles, some management plans emphasize protection of natural values. An outstanding example in New Mexico is Sevilleta National Wildlife Refuge, in which the acreage reserved for natural and research goals exceeds that of all the designated research natural areas combined. Similarly, much of the area of national parks and monuments is managed mainly for preservation of natural features. This report addresses formally designated Research Natural Areas.

Management and Use

Agencies have developed similar regulations to protect scientific and educational values in Research Natural Areas. Because the guiding principle is to prevent unnatural encroachments, human manipulation is discouraged. In an RNA one expects no construction of buildings, roads, or trails; no grazing by livestock; no woodcutting; and no programs of fire hazard reduction or reforestation. Control of insects, diseases, and fire is permitted to protect adjacent resource values. Public uses, such as picnicking and camping, that might impair natural values are generally discouraged. Policies vary on providing interpretive signs for the public. Hunting and fishing often are not regulated; but, in New Mexico, most RNA's are in refuges or monuments that regulate or prohibit these activities.

Scientists who wish to use an RNA should obtain permission from the appropriate agency. For Central Peloncillo RNA, both agencies listed should be contacted. For Forest Service RNA's, research proposals should go to the Rocky Mountain Forest and Range Experiment Station; but, on-the-ground activities should be coordinated with the National Forest. Scientists should inform the agency of progress, of published results, and of the disposition of any materials collected.

Distribution

As of early 1983, New Mexico has 17 RNA's (table 1). Six are in adjacent pairs and one, although not adjacent, is a 2-acre addendum to a larger RNA (fig. 1). Therefore, effectively, the State has 13 RNA's; but all 17 names are used in this report.

The areas are in 8 of New Mexico's 33 counties. One is in forest, 1 in lava shrubland, 3 in plains steppe or shrubsteppe, 4 in semidesert shrubsteppe, and 8 at lake or river sites.

Most RNA's in New Mexico, like Bitter Lake and Rio Grande Marsh, were designated to protect rare or unique features, rather than to create a system that represents "all significant natural ecosystems." All but one of the RNA's are at relatively low elevations. No alpine tundra nor any of the State's many subalpine forest and meadow ecosystems is included in a natural area. However, the Forest Service proposes to redress some of these deficiencies.

Sources of Information

This report outlines noteworthy features of each Research Natural Area and gives sources for further information. Some of the reference materials are based on studies that were near but not in the RNA's. Several general references, applicable to areas throughout New Mexico, are listed here but are not cited repeatedly through the report. Scientific names of trees, birds, and larger mammals are not usually stated because the common names are fairly standard in familiar manuals.

Introductory material above is in part from the 1977 publication of the Federal Committee on Ecological Reserves, National Science Foundation, "A Directory of Research Natural Areas on Federal Lands of the United States of America." The Directory (p. 142–149) summarizes the (then) 15 Research Natural Areas of New Mexico and prescribes abbreviations for them. This report expands and corrects the Directory's summaries.

Aerial photographs of the areas are available for viewing at appropriate administrative offices and usually also at the nearest Soil Conservation offices, including those in Raton, Silver City, Socorro, and Albuquerque. Aerial imagery may be purchased from the U.S. Geological Survey and, for forest areas, from the U.S. Department of Agriculture. A convenient source from nongovern-

Table 1.—New Mexico Natural Research Areas.

RNA	County	Elevation (feet)	Feature
Aden Lava Flow	Doña Ana	4,300	Lava flow
Apache Camp	Socorro	4,500	Floodplain
Bitter Lake	Chaves	3,500	Playa lake
Central Peloncillo	Hidalgo	5,800	Desert mountains
Chupadera	Socorro	5,500	Desert mountains
Gallinas	San Miguel	6,200	Plains plateau
Gila River	Grant	4,600	River canyon
Inkpot	Chaves	3,600	Sinkhole
Jornada del Muerto	Socorro	4,700	Sand plain
Lake Lucero	Dona Ana	3,900	Desert playa
Lake St. Francis	Chaves	3,500	Sinkholes
Mathers	Chaves	4,200	Sand plain
Maxwell	Colfax	6,000	Playa lake
Monument Canyon	Sandoval	8,200	Mountain plateau
Rio Grande Marsh	Socorro	4,500	Ox-bow lake
San Pascual	Socorro	5,100	Desert mountains
Vegosa	San Miguel	6,500	Plains plateau

ment scientists is the Technology Application Center of the University of New Mexico in Albuquerque.

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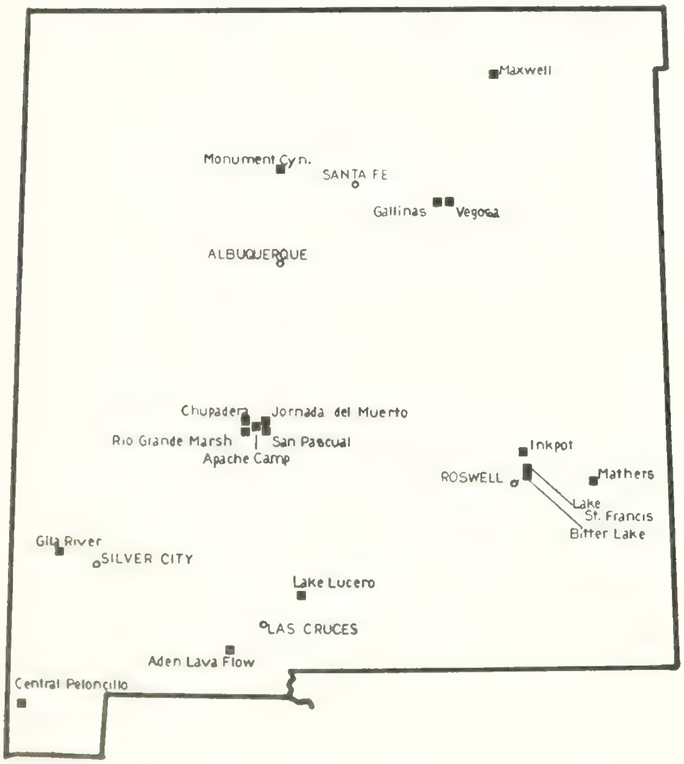

Figure 1. Research Natural Areas in New Mexico.

ADEN LAVA FLOW RESEARCH NATURAL AREA

The Aden Lava Flow, less than 100,000 years old, consists of basalt flows with a crater, spatter cones, crevasses, ridges, vents, herraduras, and other features covering about 30 square miles of a plain southwest of

Las Cruces. The shrub-grass community of the flow supports a complex array of animal life in this 4,000-acre RNA. Because of the surrounding desert, isolated animal populations of the flow, such as rock pocket mouse and black-tailed rattlesnake, can develop special characteristics.

Administration

Resource Area Manager
Las Cruces/Lordsburg Resource Area
1800 Marquess St.
P.O. Box 1420
Las Cruces, NM 88004 (505) 523–5571

Aden Lava Flow is in the Southern Rio Grande Planning Area. The Las Cruces/Lordsburg Resource Area is part of the Las Cruces District, Bureau of Land Management, U.S. Department of the Interior. The 4,008-acre (1,623-hectare) RNA was designated May 25, 1978, with an acreage correction issued in the Federal Register for November 2, 1978.

The area is open to the public without permit and is open in season for hunting. By an order issued September 23, 1980, off-road vehicles were restricted to designated roads and trails. All mineral rights are federal, and the area is open for mineral leasing. Geothermal leases for the area issued in 1975 have been dropped or have expired.

The 1977 management plan for the natural area called for 14 miles of perimeter fencing, 3 miles of road destruction and reseeding, and 5 interpretive signs. None of this has been done.

Plans called for elimination of livestock from the RNA, which then constituted only a small part of a grazing allotment. In 1981 two pastures, Afton and Malpais, of the original allotment became a separate allotment. The RNA now constitutes about 40% of this 10,000-acre ranch unit. "Because of this and the de-emphasis of the RNA program it is highly unlikely that implementation of the Aden Management Plan will take place" (Harkenrider 1983).

Location and Access

Aden Lava Flow Research Natural Area is in Doña Ana County, centered at lat. 32°04′45″ N., long. 107°02′00″ W., (fig. 2). The 4,008 acres are in T. 25 S., R. 2 W., including all of sec. 34 and 35; in sec. 33 the E1/2 of the NE1/4 and the SE1/4; and in sec. 36 the S1/2: and in T. 26 S., R. 2 W., including in sec. 3 the S1/2 of the N1/2, and the S1/2, and Lots 1–4; in sec. 4 the S1/2 and Lots 5–7 and 9–12; in sec. 5 the SE1/4 and Lots 11–12; in sec. 8 the N1/2 of the NE1/4 and the SE1/4 of the NE1/4; in sec. 9 the N1/2; and in sec. 10 the N1/2.

Access roads within 15 miles of the lava flow are unpaved and can be rough. One route uses the Corralitos exit from Interstate 10 about 2 miles west of Las Cruces; then 16 miles southwest on a county road (BLM #3223) to the locality called Kenzin on the Southern Pacific Railroad; then across the tracks and southwest for 1.5 miles to the RNA, and another 3 miles skirting its western border till a branch road turns east, into the RNA, to Aden Crater. Turning southeast after crossing the railroad leads to the northeast corner of the RNA.

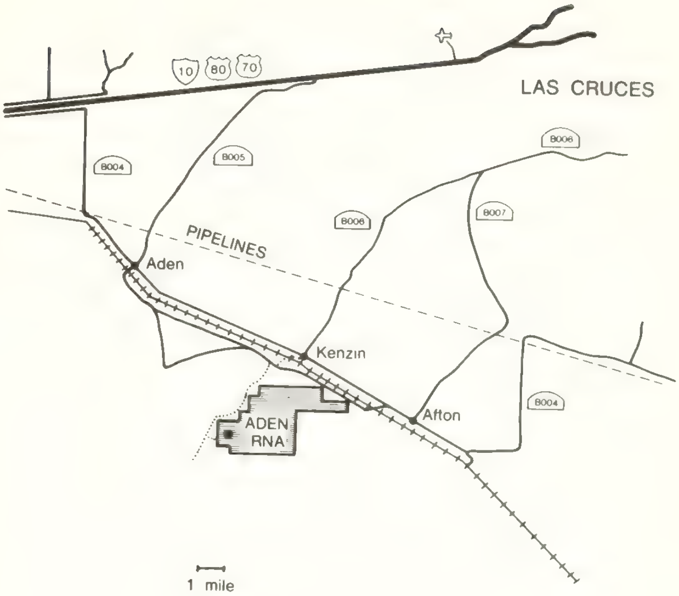

Figure 2. Aden RNA.

From Las Cruces one may also cross the Rio Grande on Mesilla Dam Road and continue west for 8 miles to join the above-mentioned county road.

Accommodations are in Las Cruces.

Climate

This is a hot, arid plain, with a mean temperature measured at Las Cruces of 59°F (15°C) and average annual precipitation of 8 inches (203 mm). Monthly average temperature data from New Mexico State University, 19 miles northeast of the RNA (Station 8535), and monthly average precipitation data from near Afton, 6 miles east of the RNA (Station 0125), are shown in figure 3.

The record high temperature 109°F, the low −10°F. Most precipitation comes in summer thundershowers, of which about 42 are expected each year. About 80% of daylight hours are clear. Climate is discussed further by Bulloch and Neher (1980), Malm and Houghton (1977), and by USDI BLM (1975, 1976, 1981).

Physiography, Geology, Soils

This is the Mexican Highland section of the Basin and Range Province. Aden Lava Flow is in the Rio Grande drainage on the La Mesa surface, a relatively flat bolson plain of mid-Pleistocene age, 300–400 feet above the Rio Grande (Hoffer 1975a). Most of the RNA is at about 4,300 feet (1,311 m.) elevation, with depressions somewhat below 4,275 feet (1,379 m.). Microrelief varies from smooth (in the eastern part where the RNA boundary goes north of the lava) to steep-walled fensters that may be 100 feet wide and 50 feet deep. There are jagged ridges and, where flow patterns allowed for separation of the lava, crevasses nearly 30 feet deep and up to 5 feet wide. Aden Crater, the most prominent feature in the area, is a shield cone (DeHon 1965) 3 to 4 miles in diameter, made up of thin basaltic flows sloping from the cone with dips of 3 to 5°. The rim is composed of spatter layers dipping 30 to 45° toward the center of the crater (fig. 4), (Hoffer 1975b). On the rim are spatter cones, a collapse depression, a 130-foot deep fumarole, and jagged rocks and crevasses. Several explosion craters are southeast of Aden Crater, and near them herraduras (Hoffer 1971) and an hornito.

The lava, which covers 90% of the RNA, was extruded in at least two separate periods, both younger than nearby Afton lava flows that have been dated at 103,000 ± 84,000 years. The low viscosity of this pahoehoe lava is indicated by the fact that some of the lava tubes and tongues are only 6 to 18 inches wide and several hundred feet in length (Hoffer 1975b). Renault (1970) calculates a solidification index of about 40 and infers rapid ascent of the magma. It is thought that the Aden flows were emplaced along fissures associated with the north-south Robledo fault and the northwest-southeast Aden rift, which intersect at or near Aden Crater. The Aden flows are part of the Potrillo basalt field discussed by Hoffer (1976).

A geothermal resource is associated with the volcanism of the area and has attracted commercial attention, but interest has declined because temperature requirements could not be met (Harkenrider 1983, USDI BLM 1975).

Much of the natural area is devoid of soil and classified as Lava Rockland. Pockets of soil are Torriorthents, and range from thin layers to several feet in depth on about a fourth of the landscape (Bulloch and Neher 1980). Simona-Harrisburg Association soils occupy the non-lava segment of the RNA.

Vegetation

At least 23 shrub species are conspicuous on the lava, including prominently creosotebush (*Larrea*), snakeweed (*Gutierrezia*), yucca (*Yucca baccata*), jointfir (*Ephedra trifurca*), saltbush (*Atriplex canescens*), and tarbush (*Flourensia cernua*), with a scattering of juniper (*Juniperus monosperma*). Common grasses include tobosa (*Hilaria mutica*), black grama (*Bouteloua eriopoda*), sideoats grama (*B. curtipendula*), hairy grama (*B. hirsuta*), mesa dropseed (*Sporobolus flexuosus*), bush muhly (*Muhlenbergia porteri*), and fluffgrass (*Erioneuron pulchellum*) (fig. 5). Off the lava, mesquite (*Prosopis glandulosa*), soap tree (*Yucca elata*) and snakeweed dominate. Species lists based on collections by T. Van Devender and others are in USDI BLM (1976), as is a short list of lichens.

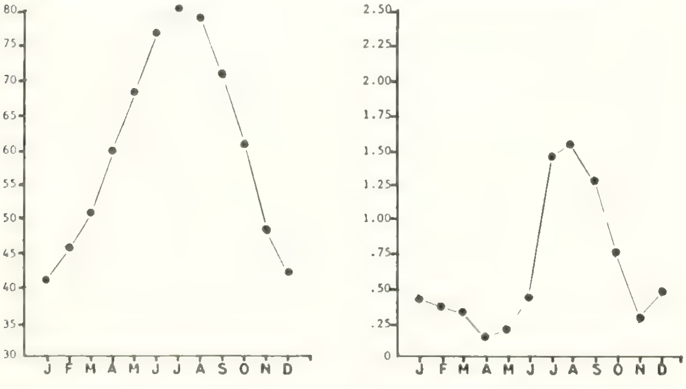

Figure 3. Climate of Aden Lava Flow RNA.

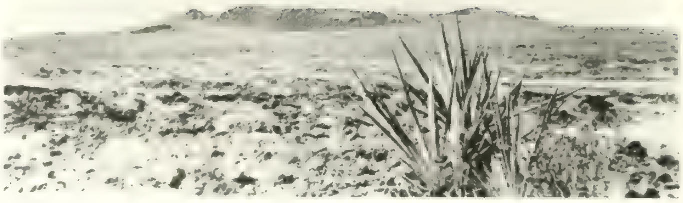

Figure 4. Aden Crater from the northeast. Aden Lava Flow RNA. (From Hoffer 1976, courtesy of J. M. Hoffer.)

Animals

M. McKirnerey and W. H. Reid compiled a list of 48 mammal species that are probably in the area (USDI BLM 1976), including 9 rodent species studied here by Koschmann (1972) and 14 other species sighted in the vicinity of Aden Crater. Common are desert cottontail, black-tailed jackrabbit, coyote, and California myotis; as many as 12 bat species are expected because of the many crevices and small caves. Ten carnivore species are listed, including sightings of coyote, gray fox, ringtail, western spotted and striped skunks, and bobcat. Mule deer and pronghorn occur but are uncommon.

Some rodents in the lava flow show melanistic changes, in particular the rock pocket mouse (*Perognathus intermedius*). Benson (1933) and Koschmann (1972) have studied these dark races.

McKirnerey and Reid (in USDI BLM 1976) list 38 bird species for the lava flow, including 10 raptor species. Turkey vultures nest in vent tubes southeast of Aden Crater.

The environmental analysis record (USDI BLM 1976) also includes lists of reptiles and amphibians, but the occurrences are mainly speculative rather than confirmed. Melanistic black-tailed rattlesnakes have been studied on the flow (Prieto and Jacobson 1968).

A well-preserved Shasta ground sloth was found in the deep fumarole of Aden Crater (Lull 1929) and has been dated about 11,000 years before the present (Simons and Alexander 1964).

Intrusions and Threats

A north-south fence crosses section 35, and a trail open to off-road vehicles meets it from the northeast. A 2-track road from the west reaches the rim of Aden Crater. Sightseers and their vehicles might be counted as intrusions, and the Southern Pacific railway, though 0.25 miles or more north of the natural area, surely seems to be one.

The area was leased for geothermal production in 1975, but there was no development. The leases have terminated; however, the area has not been withdrawn from leasing as BLM planned.

Cattle, past and present, are probably the main intrusion. The vegetation shows signs of past overgrazing. The plan to eliminate grazing has been shelved, and in fact made difficult by realignment of grazing allotments. About 2.5 cattle yearlong are permitted per 640-acre section in the allotment. The proposed allocation of federal grazing capacity of the allotment is 227 animal unit months for livestock and none for big game, increasing by the year 2019 to 338 for livestock and none for big game (USDI BLM 1981).

Research

Considerable research has been and is being done in the area, much of it by faculty of the University of Texas—El Paso, in geology (Hoffer, 1971, 1975a, 1975b) and in biology. USDI BLM (1976) mentions ongoing research on behavior of carnivores, Townsend's big-eared bat, and Pleistocene faunal sites. Chaves (1983) is working on topographic and edaphic relations of vegetation on the flow. Sources below report additional geological work near Aden Crater.

Maps

Topographic: U.S. Geological Survey 1:62,500 series, Aden Quadrangle, 1941, and, for the easternmost 160 acres, Afton Quadrangle, 1941. Geological: Hoffer (1975b, 1976) and Kottlowski (1953). Vegetation: maps such as that in USDI BLM (1975b) merely differentiate malpais vegetation from non-malpais. Soils: Bulloch and Neher (1980). Aerial photography: Bulloch and Neher (1980).

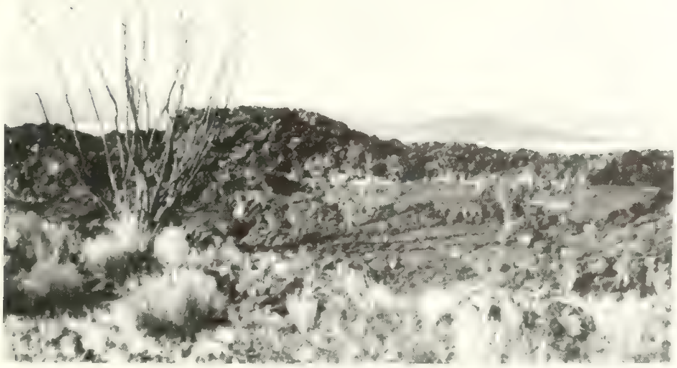

Figure 5. A crater rim and typical vegetation. Aden Lava Flow RNA.

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APACHE CAMP RESEARCH NATURAL AREA

This strip of Rio Grande riparian vegetation, 3 miles long and less than 1,000 feet wide, suffers take-over by saltcedar and drowning by water backed up from a channelization project. It provides waterfowl, raptor, songbird, and mule deer habitat. Cottonwood dominates "upland" (8 feet above "lowland") parts of the area, with saltcedar and saltgrass or sacaton understories.

Administration

Refuge Manager
Bosque del Apache National Wildlife Refuge
P.O. Box 1246
Socorro, NM 87801 (505) 835–1828

Apache Camp is one of the 5 natural areas in Bosque del Apache Refuge, a 57,191-acre unit of the National Wildlife Refuge System administered by the Fish and Wildlife Service, U.S. Department of the Interior. The Refuge was established in 1939. These "220 acres" (89 hectares; but in fact probably closer to 260 acres—105 hectares—with the given boundaries) were designated a Research Natural Area August 17, 1973.

Public access is allowed during daylight hours. Mule deer hunts with primitive weapons are allowed in this part of the Refuge in some years. No livestock grazing is permitted on the Refuge. This is New Mexico's only RNA with public facilities: toilets are maintained by the tour loop road in the north end of the area. The RNA is neither fenced nor posted.

Location and Access

Apache Camp RNA is in Socorro County, centered at lat. 33°48′40″ N., long. 106°51′30″ W., (fig. 6). Were the area surveyed it would be in T6S R1E. The RNA extends north along the Bosque del Apache Wildlife Refuge tour loop road for 3 miles from its junction with the road that crosses the Rio Grande Main Conveyance Channel. At that southern end the RNA is 480 feet wide, widening northward to 900 feet, which is nearly constant for most of the length of the RNA. West and south boundaries are graded roads. The east boundary is a 2-track road along the west side of the Conveyance Channel; it is gated, locked, and at least during 1981–1982 was partly under water. The north boundary is a revegetating road and dike from the northern extremity of the tour loop to the Conveyance Channel.

Apache Camp is 88 miles from Albuquerque and 137 miles north of Las Cruces. From the north, turn off Interstate 25 on US 380 for San Antonio (10 miles south of Socorro); from the town of San Antonio follow Refuge signs 8 miles south on N.M. 1 to headquarters of Bosque del Apache refuge. From the south turn off I–25 for San Marcial and follow N.M. 1 north for 12 miles to Refuge headquarters. From headquarters turn east (open only during daylight hours) and head as nearly as possible east on tour loop roads for 1.35 miles, where this two-way segment of tour loop road system ends at the southwest corner of the RNA. The length of the RNA may be driven on either east or (better) west side.

Accommodations are in Socorro.

Climate

This is a warm region with arid climate (Campbell and Dick-Peddie 1964; Houghton 1972). Precipitation averages 8 inches (200 mm.) annually, very little of it snow. July through September account for 47–60% of the precipitation. Mean temperature is 58°F (14°C); the highest temperature recorded was 113°F (45°C) and the lowest −9°F (−23°C). Monthly averages from the weather station at Refuge headquarters (Station Index 1138), 1.5 miles west of and a few feet above the RNA are shown in figure 7.

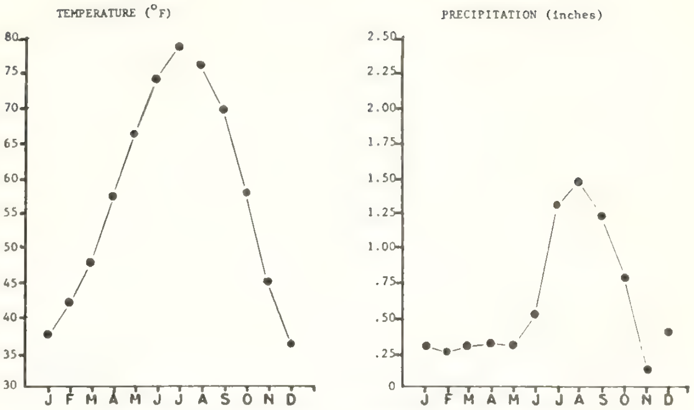

Figure 7. Climate of Apache Camp RNA.

Physiography, Geology, Soils

Apache Camp RNA is in the floodplain of the Rio Grande, which here traverses the Basin and Range Province through a rift valley (Hawley 1978). In 1929 the river flowed across the southern part of what is now the RNA, and an oxbow lake lay farther north within the area (Poulsen and Fitzpatrick 1931). Small banks and marshes remain as witnesses to these vicissitudes. Now the river is thought to have been tamed; a straight channel lies along the east side of the RNA. In 1981–1982 work on that channel downstream backed water onto the southern quarter of the RNA; saltcedar and ducks are the principal survivors.

The Rio Grande used to go dry frequently here; for instance an average of 39 days per year during 1916–1927 (Poulsen and Fitzpatrick 1931). The natural channel still goes dry, but flow is relatively steady in the Main Conveyance Channel, 10 feet east of the Apache Camp RNA boundary.

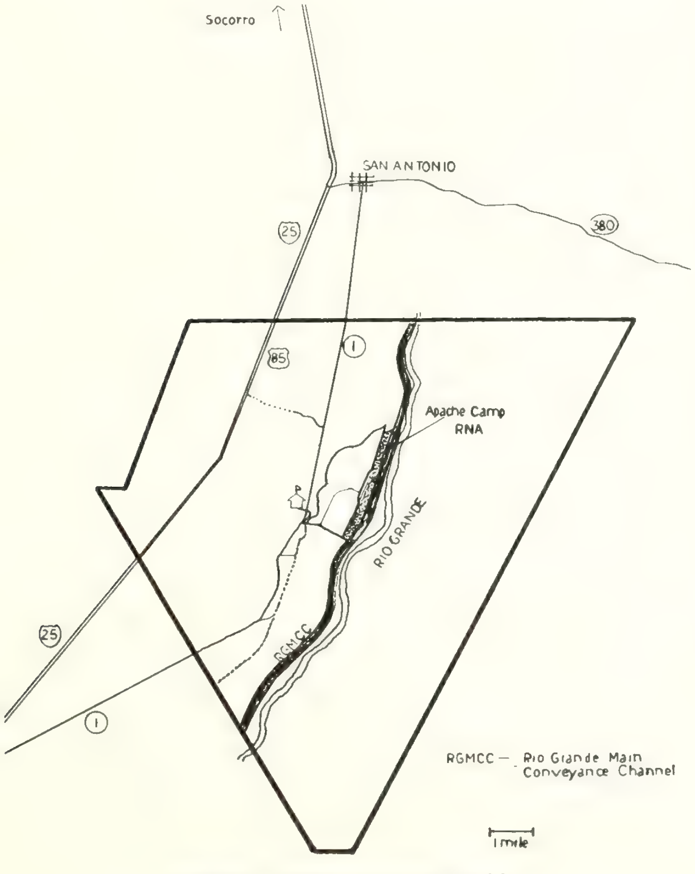

Figure 6. Apache Camp RNA.

Elevations range from the southern water level at about 4,508 feet (1,374 m.) to banks reaching 4,516 feet (1,377 m.) at the north end.

Recent river deposits cover the area, and soils, if any, are young. Maker et al. (1972) classify soils of the floodplain—an entisol bottomland—in the Gila-Vinton-Glendale Association. The RNA appears to have mainly alkaline (Gila?) clay and silt. The soil regime is thermic; great groups represented are Torrifluvents, Calciorthids, and Torriorthents.

Vegetation

Evidence suggests that Rio Grande cottonwoods (*Populus fremontii* var. *wislizenii*) dominated this area some decades ago, and they still dominate parts of it (fig. 8). However, fire (mostly recently in 1978) and the invasion of saltcedar (*Tamarix gallica*), beginning mainly in the 1940's, have taken a heavy toll. The southern end of the RNA, under water in 1981–1982, has only saltcedar and a few aquatic and marsh plants (fig. 9). Northward are varying mixes of cottonwood and saltcedar with scattered tornillo (*Prosopis pubescens*), black or Goodding willow (*Salix nigra* including *S. gooddingii*) and Russian olive (*Eleagnus angustifolia*), the last, like saltcedar, a Eurasian species. Low shrubs include wolfberry (*Lycium*) and coyote willow (*Salix exigua*). Prominent grasses are alkali sacaton (*Sporobolus airoides*) and saltgrass (*Distlichis spicata*), with some three-awn (*Aristida longiseta*). But much of the ground is bare under the tree-shrub layers.

A few seasonally dry depressions support wetland vegetation, notably cattails (*Typha*), saltgrass, and rabbitfoot grass (*Polypogon monspeliensis*).

The potential natural vegetation is Forest Cover Type 235, cottonwood-willow (Eyre 1980). Campbell and Dick-Peddie (1964) discuss riparian communities of this area.

Animals

Many birds nest or feed here, including (so long as part of the RNA is flooded) waterfowl and wading birds.

Mourning doves are common. The large cottonwoods are home to songbirds and raptors (USDI—FWS 1982).

Mule deer, rock squirrels, and whiptail lizards are among the conspicuous animals. No doubt there is a diversity of amphibians and reptiles, but data are not available.

Archaeology

The immediate vicinity is known as an Apache camping area.

Intrusions and Threats

Intrusions appear to outnumber natural features. Dikes, canals, and roads surround the area. Four-foot-high dikes poke into it from both sides, and there are piles of earth from the canal on the east side. Introduced saltcedar is by far the most common woody plant here, abetted by man-caused flooding. Public toilets were built in the area the year it was designated an RNA.

Research

None is known for the RNA.

Maps

Administrative: consult Refuge headquarters. Topographic: USDI—Geological Survey 1:24,000 series, San Antonio SE Quadrangle, 1982. Soils: Poulsen and Fitzpatrick (1931); Maker et al. (1972). Geology: Bachman and Stotelmeyer (1967). For aerial photography consult the Refuge management or the Soil Conservation Service office in Socorro.

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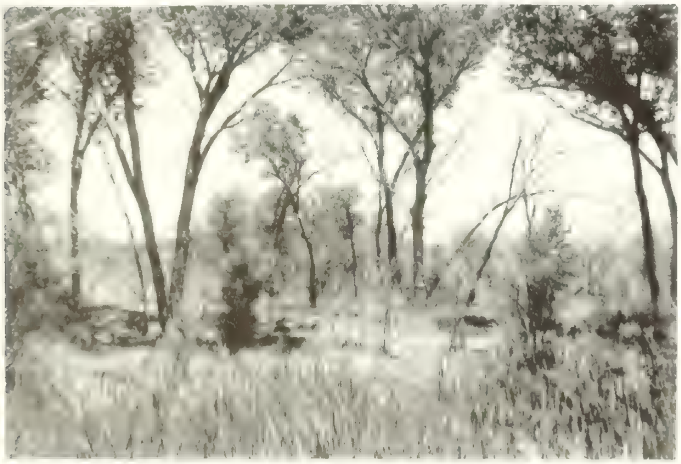

Figure 8. Cottonwoods above saltcedar and cattails. Apache Camp RNA.

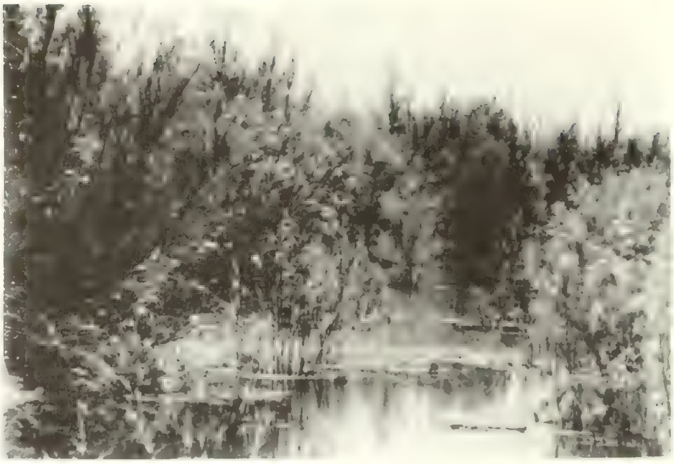

Figure 9. Inundated saltcedar. Apache Camp RNA.

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BITTER LAKE RESEARCH NATURAL AREA

Bitter Lake—or, by late summer, the dry, white Bitter Lake playa—covers half of the natural area's 300 acres. In winter, large numbers of waterfowl, sandhill cranes, and migratory shorebirds inhabit the lake, and several shorebird species remain year-round. In gypsum beds west of the lake, springs and small, brackish streams flow through sinkholes inhabited by three uncommon minnows: Pecos gambusia, greenthroat darter, and Pecos pupfish.

Administration

Refuge Manager
Bitter Lake National Wildlife Refuge
P.O. Box 7
Roswell, NM 88201 (505) 622–6755

The Refuge is a unit of the National Wildlife Refuge System administered by the Fish and Wildlife Service, U.S. Department of the Interior. The Refuge was established in 1937. Bitter Lake Research Natural Area was designated 17 August 1973. It comprises about 300 acres (121 hectares). Entry requires a permit from the Refuge Manager except to the observation platform at the southwest corner of the natural area. Hunting, fishing, and livestock grazing are prohibited. Mineral rights in the RNA are federally owned, but this is not true for Section 32, 0.3 miles north of the RNA. The research natural area is not marked as such, but there are "no unauthorized entry" signs at strategic points.

Location and Access

Bitter Lake Research Natural Area is in Chaves County, centered at lat. 33°28′20″ N., long. 104°24′30″ W., in T. 10 S., R. 25 E., secs. 4 and 5, (fig. 10). Beginning at the intersection of a Refuge road with No. 2 Impoundment in the SW1/4 of the NE1/4 of sec. 4, the boundary is described as S 15° W for 1,000 feet, thence S. 37° E. for 1,750 feet, thence S. 41° W. for 600 feet, thence W. for 4,200 feet, thence N. for 2,850 feet, thence E. for 3,800 feet to point of beginning.

The RNA is a mile north-northwest of headquarters in the south tract of Bitter Lake National Wildlife Refuge, 14 miles northeast of Roswell. From Roswell or from the east a road leading to the Refuge turns north from U.S. 380, 3.8 miles east of Main Street. From Roswell or from the north a road leading to the Refuge turns east from U.S. 70–285 (= Main Street) 4 miles north from U.S. 380 (= Second Street); follow Refuge signs as the route turns northeast after 0.6 miles, then east again after another 2.4 miles.

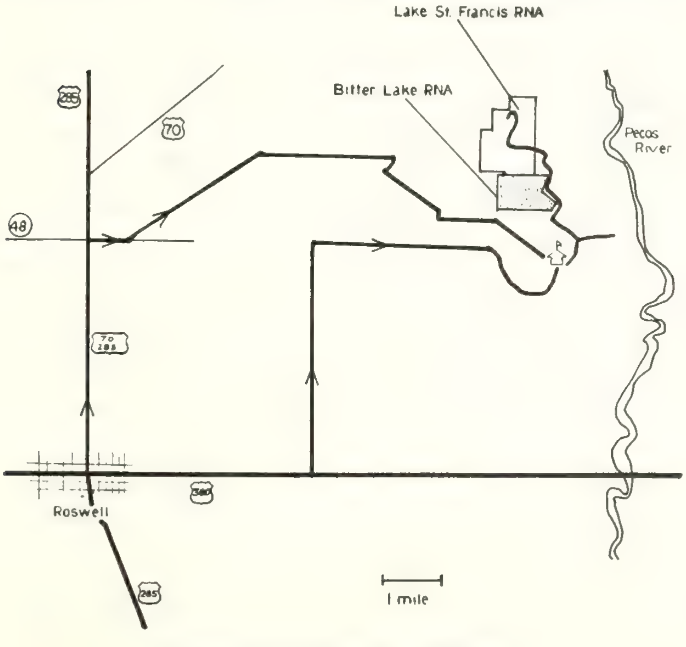

Figure 10. Bitter Lake RNA.

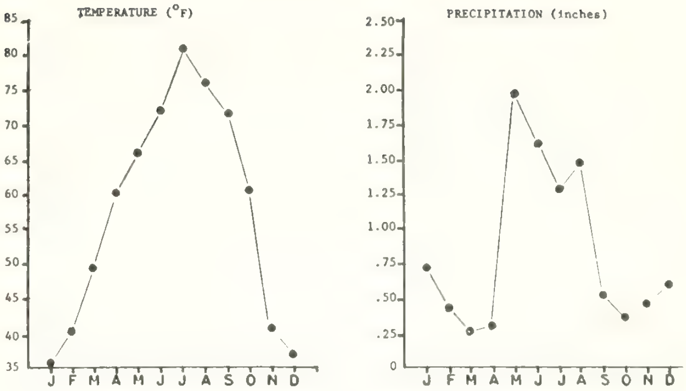

Figure 11. Climate of Bitter Lake RNA.

Given an entrance permit, the southwest corner of the natural area can be reached by car from the west entrance road. East, north, and west sides of the RNA are reached by a road through the headquarters area.

Accommodations are in Roswell.

Climate

The Refuge is in a warm desertic region, with mean temperature 58°F (14°C) and average precipitation 10 inches (250 mm.) per year measured at the Refuge, or 13 inches (330 mm.) per year measured over a longer period near Roswell. Sunshine averages 70% of the amount possible for the year. The record high temperature at the Refuge is 112°F (44°C) and the low −12°F (−24°C). Climate is discussed by Houghton (p. 138–141 in Hodson et al. 1980) and by Mourant (1963). Monthly averages from Refuge headquarters (Station Index 0992), 1 mile from the RNA are shown in figure 11.

Physiography, Geology, Soils

Bitter Lake is in the Pecos Valley section of the Great Plains Province, in the west edge of the floodplain of the Pecos River. The river's present channel is 1.25 miles to the east; a former channel with impoundments for waterfowl is adjacent to the RNA.

Only 10 feet separate high and low elevations in the natural area, 3,501 and 3,491 feet (1,067 and 1,064 m.). Depth of the playa lake that covers about half the RNA varies from 0 in later summer and fall to (theoretically) 4 feet. Excess over 4 feet would flow out through a spillway, but that depth has not been achieved in many years. Bitter Lake receives water from streams and springs on its west side. Of several small sinkholes there, a few contain water. The playa basin is said to be the result of subsidence a few decades ago caused by an underground stream.

The uppermost strata covering the natural area are Pleistocene and Recent alluvium, including terrace gravel and disturbed gravel. Thickness of this valley fill—all of it water-saturated, according to 1969 data—is about 150 feet (Lyford 1973). Bedrock, exposed at sinkholes and streams, is a gypsiferous layer of the Queen Formation, part of the Permian Artesia Group (Kelley 1971). The sinkholes contain superficial gypsite deposits. Water levels depend on recharge in the Roswell Artesian Basin, which in turn depends upon precipitation and water-use many miles to the west and south.

Soils are alkaline from solution of gypsum; the 150-acre lake bed is covered by a gypsum crust. Soils are characterized for the most part as shallow, pale-brown loams with a thick solum at the A2 level and high gypsum content. They are in the Holloman-Gypsumland complex, classified as Gypsiorthids and Torriorthents (Hodson et al. 1980). The moisture regime is borderline between aridic and ustic-aridic.

Vegetation

Plants must be gypsum-tolerant to grow here; a few such as gyp ring-stem (*Anulocaulis gypsogenus*) are obligate gypsophiles. On the gypsum deposits at the edge of the playa grows a vigorous stand of seepweed (*Suaeda* sp.) with sea lavender (*Limonium limbatum*), glassworts (*Salicornia* spp.) and iodinebush (*Allenrolfea occidentalis*).

On the west side of the lake where water enters is a bulrush-cattail marsh in which the tallest species, three-square (*Scirpus americanus*), is 5 or 6 feet tall (fig. 12). Marsh vegetation continues west from the shore in the wetter areas, grading into reeds (*Phragmites australis*) where there is no standing water. In the water are stoneworts or muskgrass (*Chara*), ditchgrass (*Ruppia maritima*), arrowgrass (*Triglochin maritima*) and pondweed (*Potamogeton pectinatus*). Beside the small streams grow a variety of grasses such as saltgrass (*Distlichis spicata*) and alkali muhly (*Muhlenbergia asperifolia*) and herbs such as prairie gentian (*Eustoma exaltatum*) (fig. 13). Saltcedar (*Tamarix*) has invaded since a 1937 survey (Campbell 1937), and is found scattered near most shores of Bitter Lake and near sinks and streams.

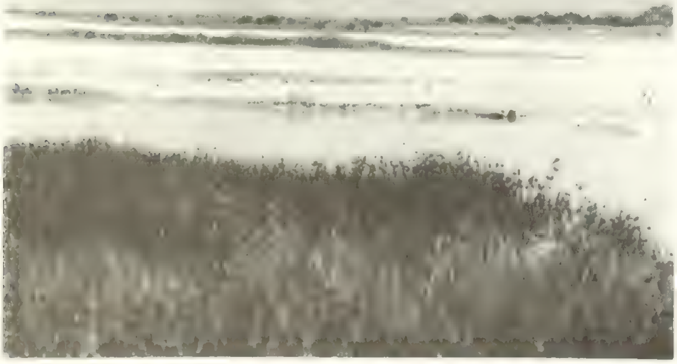

Figure 12. Bulrushes at the west end of mostly-dry Bitter Lake.

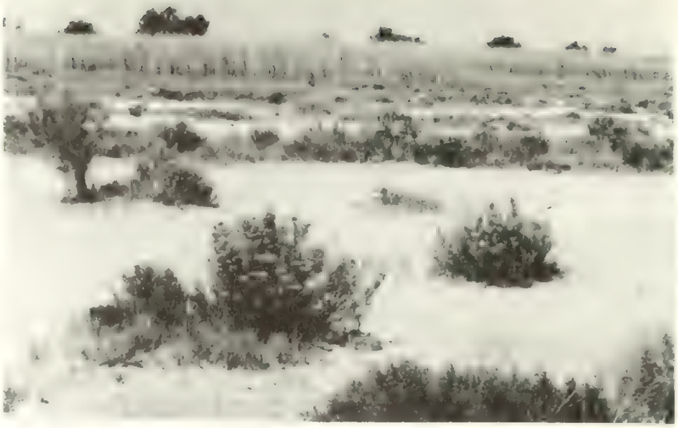

Figure 13. Saltgrass and shrubs at the playa's edge, with reeds and salt cedar in the background. Bitter Lake RNA.

Away from the water sacaton (*Sporobulus* spp.), gramas (*Bouteloua* spp.), and other grasses dominate, but with many herbs such as *Sartwellia flaveriae* and low shrubs such as *Clappia suaedifolia*. For this upland vegetation see also discussion of the adjacent Lake St. Francis RNA.

Animals

Bitter Lake Refuge is the most important waterfowl concentration point in eastern New Mexico, and water birds use Bitter Lake in abundance. Almost 300 bird species have been recorded at the Refuge (USDI—Fish & Wildlife Serv. 1976, Hubbard 1978), of which the chief lake-users are Canada goose, snow goose, mallard, gadwall, blue-winged teal, wigeon, shoveler, ruddy duck, coot, lesser sandhill crane, ring-billed gull, herons, and snowy egret. The locality is especially important for the lesser sandhill crane, of which 70,000 have been counted at one time on Refuge roosts. Their presence peaks in October-December. Shorebirds that nest here include snowy plover, killdeer, avocet, and black-necked stilt.

Three minnow species inhabit the springs and sinks west of Bitter Lake; all three are in the sink fed by Sago Spring, and various combinations of species are in the other waters (Hubbs and Echelle 1972). The Pecos gambusia (*Gambusia nobilis*) is listed as endangered by the Fish and Wildlife Service and as threatened by the New Mexico State Game Commission; the greenthroat darter (*Etheostoma lepidum*) is listed as endangered by the state; and the Pecos pupfish (*Cyprinodon pecosensis*), though no longer listed as threatened, is also a species of restricted and rather uncertain Pecos Basin habitats (Bednarz 1975, Echelle and Echelle 1978, Hubbard et al. 1979, Hubbs and Echelle 1972). Micro-distributions of the minnows in the Refuge ponds have been affected by transplant experiments in 1973 and 1981.

Desert cottontail, black-tailed jackrabbit, striped skunk, raccoon, bobcat, coyote, gray fox, badger, and long-tailed weasel are among the mammals noted for this part of the Refuge (USDI—Fish & Wildlife Serv. 1976).

Invertebrates have been studied in a sulphate-rich springbrook near Roswell, similar to those of Bitter Lake RNA (Noel 1954).

Intrusions and Threats

Gravel roads reach into the RNA on the west, southwest, south, and north; but the latter two, formerly connecting across the middle of the playa, have largely been destroyed by water. Roads are maintained just outside the east and northwest boundaries of the natural area, and a parking area and observation platform are at the southwest corner. The east roadbed would serve as a dike at high water levels.

A ditch at the southeast corner would drain the lake were the depth to exceed 4 feet, since water beyond that depth is not federally owned; but there has been no flow since the ditch was dug.

Saltcedar, Russian olive, and other Eurasian plant species might also be regarded as intrusions.

Principal threat to the natural area is the decline of the watertable in the Roswell Artesian Basin in which Bitter Lake is located. Some of the small sinkholes in the west part of the RNA have dried up, and flow from springs and from Lost River, the small stream that enters the area from the west, have decreased over the years. The problem is discussed under Lake St. Francis Research Natural Area.

Research

Recent study of the minnows has been sponsored by the New Mexico Department of Game and Fish, and has also been carried out by academics including the Echelles (1978) of Baylor University and Hubbs (1972) of the University of Texas. Management research on lesser sandhill cranes is carried out here by the Department of Game and Fish.

Maps

Administrative: consult Bitter Lake National Wildlife Refuge. Topographic: U.S. Geological Survey 1:24,000 series, Bitter Lake Quadrangle, 1962; 1:100,000 series, Roswell sheet, 1979. Vegetation: Campbell (1937). Geology: Kelley (1971). Soils: Hodson et al. (1980). For aerial photography see Hodson et al. (1980).

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CENTRAL PELONCILLO RESEARCH NATURAL AREA

Sierra Madrean animal and plant species, many at or near their northeastern limits, here inhabit the rugged Peloncillo Mountains. Piedmont desert grassland, Madrean oak woodland, interior chaparral, and pinyon-juniper woodland lightly clothe rocky slopes that rise from 5,200 to 6,500 feet in elevation within the natural area. Large mammals include mule deer and Coues' white-tailed deer, javelina, feral swine, gray fox, black bear, coati, mountain lion, and bobcat. A rich reptile fauna is present, and a well-studied bird fauna of about 150 recorded species. Soils and geology—Miocene tuffs and rhyolite-welded tuffs—are also relatively well-known in the 4,348-acre RNA.

Administration

Area Manager
Las Cruces/Lordsburg Resource Area
Bureau of Land Management
P.O. Box 1420
Las Cruces, NM 88004 (505) 523–5571
and
Dr. Robert T. Scholes
Bioresearch Ranch, Inc.
P.O. Box 117
Rodeo, NM 88056 (602) 558–2330

Uniquely among New Mexico's Research Natural Areas, Central Peloncillo takes advantage of a provision in the Standards and Policy Guidelines for Research Natural Areas (Federal Committee on Ecological Reserves, 1976, Selection Criteria 2.3.1) permitting designation of private land in conjunction with a federal RNA. The federal grazing allotment that is tied to what is now Bioresearch Ranch was, at Dr. and Mrs. Scholes' instigation, retired. Designation of the area (Federal Register 2 October 1980) formally lists only the 2,468 federal acres but states that "The selection of nonuse of the grazing privileges by the base property owner and his desire to continue this practice has created an area that is essentially a giant control plot for an outdoor laboratory. This area of special worth must be protected." The Bureau issued a Central Peloncillo Research Natural Area Research Use and Management Master Plan in 1979, and concepts from it are included in the Plan Element (USDI BLM 1980) promulgated prior to designation. It calls for joint approval of prospective research by Bureau and Bioresearch Ranch and outlines permitted educational and recreational uses. Off-road vehicles, picnicking, camping, and collection are among prohibited uses. "If land or mineral interest becomes a threat, withdrawal action with subsequent segregative effects should be considered." The Bureau's district animal damage control plan establishes a buffer zone of at least 6 miles around the area to limit effects of predator trapping.

A cooperative agreement between the Bureau and Bioresearch Ranch was signed September 9, 1980, and is used in lieu of the pending joint management plan.

Lack of agreement between regulations governing designation of RNA's and the Federal Land Policy and Management Act of 1975 caused a bureaucratic quirk: this research area is technically not an RNA but an "area of critical environmental concern" *named* "Central Peloncillo Research Natural Area." No significant distinction exists, according to the BLM's State Director.

The RNA is fenced and livestock grazing has not occurred since 1972. Hunting, in season, is permitted on the public lands because of strenuous objections by the New Mexico Department of Game and Fish to the initial, 1977, closure of the area to hunting by the Bureau. Access is controlled by the private landowners.

In 1982, The Nature Conservancy acquired, through gifts, 2,010 acres of the Owl Canyon drainage north of Bioresearch Ranch. By cooperative agreement signed in December 1982 the Bureau has leased grazing privileges (which will not be used) on 620 acres of federal land in Owl Canyon to the Conservancy. For most purposes these 2,630 acres may be thought of as additions to Central Peloncillo RNA, though as of January 1983 the Bureau's Area Manager had no plans to include Owl Canyon in the RNA. For further information consult John C. Egbert, Field Office Director, The Nature Conservancy, P.O. Box 1846, Albuquerque, NM 88103; (505) 242–2015.

Location and Access

Central Peloncillo Research Natural Area is in southwestern Hidalgo County about 9 miles southeast of Rodeo (fig. 14). It is centered at lat. 31°43′5″ N., long. 108°56′45″ W. The RNA is in T. 30 S., R. 21 W., including all of sec. 1–2 and 10–12 and parts of sec. 3 and 9; and T. 30 S., R. 20 W., parts of sec. 6–7 and 18.

At this writing there is no public right-of-way. Visits should, in any event, be arranged in advance with the Bioresearch Ranch, which has headquarters at the RNA. The Ranch entrance is an east turn from U.S. 80 5.5 miles southwest of Rodeo onto a dirt road to the headquarters in upper Post Office Canyon, about 7.5 miles from U.S. 80 (passing the Miller Ranch headquarters at about 5.3 miles from the highway).

Accommodations are in Douglas and Portal, Arizona, and in Lordsburg. Researchers may be able to arrange camping with Bioresearch Ranch.

Climate

The area is warm and semi-arid, at least at lower elevations. At Rodeo, 9 miles northwest of and 1,100 to 2,500 feet lower than Central Peloncillo RNA, annual precipitation averages 11 inches (285 mm.). At Chiricahua National Monument, 30 miles west of, but at the same elevation as the canyons of Central Peloncillo, the corresponding figure is almost 18 inches (450 mm.). Climatic data taken at Bioresearch Ranch since 1972 are summarized in figure 15. Precipitation is clearly concentrated in late June–September, and the April–June foresummer is arid. Climate is discussed by Whitfield and Beutner (1938), Gillerman (1958), and Moir (1977, 1979).

Physiography, Geology, Soils

Gehlbach (1981) describes this Mexican border region. The Peloncillos are a 100-mile-long fault-block range extending north from Mexico along the Arizona-New Mexico border and finally into Arizona, characteristic of the Mexican Highlands section of the Basin and Range Province. To the east lies the Animas Valley, a closed basin (once containing a lake) at about 4,800 feet elevation, and to the west, San Simon Valley at about 4,400 feet elevation. The Peloncillos rise to 6,660 feet, with their highest peaks near Central Peloncillo RNA. Steep slopes give an appearance of greater loftiness (Gillerman 1958). In the RNA the low point, 5,200 feet (1,585 m.), and high point, the Black Mountain summit at 6,500 feet (1,980 m.), are both near the southeast corner.

The RNA includes the north-south axis of the formative anticline and also the divide between Animas Valley and San Simon Valley drainages. Some 70% of the natural area drains east, mostly through Maverick Canyon. Maverick Spring is about a mile above the canyon mouth near the center of the east boundary; it is permanent and is the area's principal source of surface water, maintaining its flow for about half a mile to a dam site. There is also a small but permanent impoundment in the southeast corner of the RNA (Moir 1977).

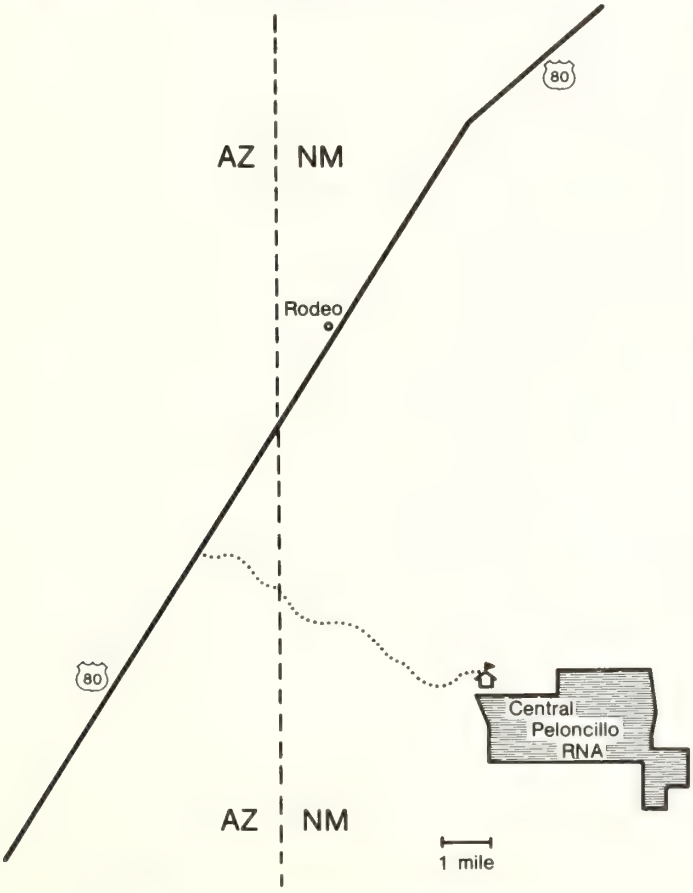

Figure 14. Central Peloncillo RNA.

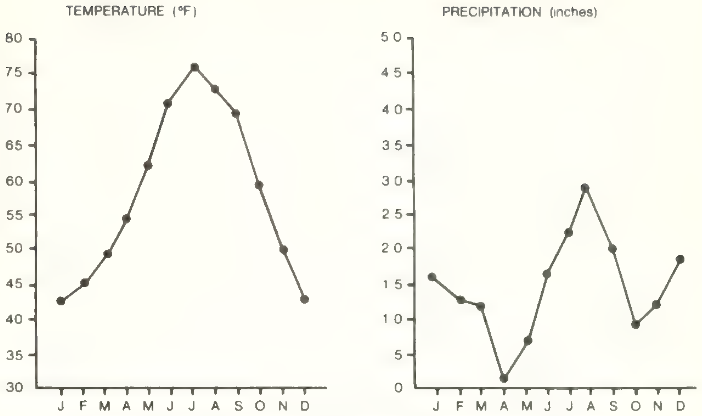

Figure 15. Climate of Central Peloncillo RNA.

The core of the Peloncillos is Precambrian, and Precambrian and Paleozoic strata are exposed north of Rodeo; but in the vicinity of the RNA all exposures are Miocene volcanics. Wrucke and Bromfield (1961) use three map units for what is now the RNA: (1) about 20% of the area is "rhyolite tuffs and welded tuffs," white to light red, containing many annular lapilli; (2) about 75% is "rhyolite welded tuff," pale red-purple to red-brown, with many quartz and sanidine crystals 1 mm. in diameter; and (3) about 5% is rhyolite tuff, poorly compacted, with many angular lapilli, forming the conspicuous cliffs of Skull Canyon. Geology of areas a few miles north is discussed in detail by Gillerman (1958) and by Armstrong et al. (1978), with many data applicable to the RNA. Ross and Smith (1961) and Marjaniemi (1969) discuss the ash-flow origin of most of these tuffs. The Peloncillos were uplifted as a horst block at about the same time as the eruptive volcanic events. No significant mineral deposits are known near the RNA.

Upland surfaces are highly eroded. There are accumulations of alluvium in some canyon bottoms, but others are scoured clean. There are few or no deep soils. Cox (1973) maps the whole area as "rough broken land and rock land," described as acid-igneous, nearly everywhere cobbly and stony, with slopes from 25% to 75%. Moir (1979, 1980) studied soils of the vicinity of the RNA in some detail, and identifies 13 types: Argiustolls, Haplustolls, Haplargids, Ustifluvents, and Usterthents in typic, eroded, aridic, cumulic, or ustollic phases, in addition to the prominent "bare rock" soil.

Vegetation

Moir (1979) discusses vegetation under five general headings: piedmont desert grassland, interior chaparral, Madrean oak woodland, pinyon-juniper woodland, and rock land vegetation. His paper gives species lists, correlations with soil and other site factors, and a map of vegetation that covers the northwest corner of the RNA, around Post Office Canyon. The following paragraphs summarize (and modify slightly) Moir's report.

Piedmont desert grassland is extensive on colluvial and alluvial landforms of low and intermediate elevations. Gramas (*Bouteloua curtipendula*, *B. hirsuta*, *B. gracilis*, and *B. eriopoda*) are most abundant, followed by bluestems (*Schizachyrium cirratum* and *Bothriochloa barbinodis*). Few shrubs or trees are present. The soils are Haplustolls, lacking the cobbles that are elsewhere abundant. Better grassland stands are found in the Owl Canyon area of The Nature Conservancy reserve to the north than in the RNA itself.

Interior chaparral, characterized by evergreen sclerophyll shrubs, is made up of two community types. Chaparral savanna, on eroded slopes and uplands, has shrub and grass codominants in open, savanna physiognomy. Toumey oak (*Quercus toumeyi*), manzanita (*Arctostaphylos pungens*), evergreen sumac (*Rhus virens* var. *choriophylla*), mortonia (*Mortonia scabrella*), and sacahuista (*Nolina microcarpa*) are the commonest shrubs, joined by border pinyon (*Pinus discolor*) (fig. 16); all shrubs average a total of 22% cover and perennial grasses 14%. Chaparral woodland, with more pinyon, oak, manzanita, sumac, silktassel (*Garrya wrightii*), and desert buckthorn (*Ceanothus greggii*), averages 47% shrub cover and 3% perennial grasses.

Madrean evergreen woodlands also occur in two community types. Oak savanna is on alluvial fans of the larger canyons; the 15% average tree cover is mainly Emory oak (*Quercus emoryi*), with manzanita and sacahuista runners-up in abundance. Canyon oak woodland, with 43 to 100% tree cover (average 79%), has mainly white-leaf and Arizona white oaks (*Quercus hypoleucoides*, *Q. arizonica*) with border pinyon, alligator juniper (*Juniperus deppeana*), and squaw bush (*Rhus aromatica*) also common. But some of Moir's woodland species are not confirmed by Todsen (1980) for the RNA itself, and may be from the more southerly part of Moir's study area.

Pinyon-juniper woodland is found between 5,600 and 6,400 feet elevation, usually on steep slopes (fig. 17). Border pinyon usually dominates, with alligator and one-seed junipers (the latter *Juniperus monosperma* in the widest sense of that species) and Arizona white oak. Pinyon-juniper savanna, with 4–30% tree cover, may be distinguished from pinyon-juniper woodland in the strict sense, with 35–85%. The woodier community is on deeper soils than the savanna, which is commonly on bare rock soil.

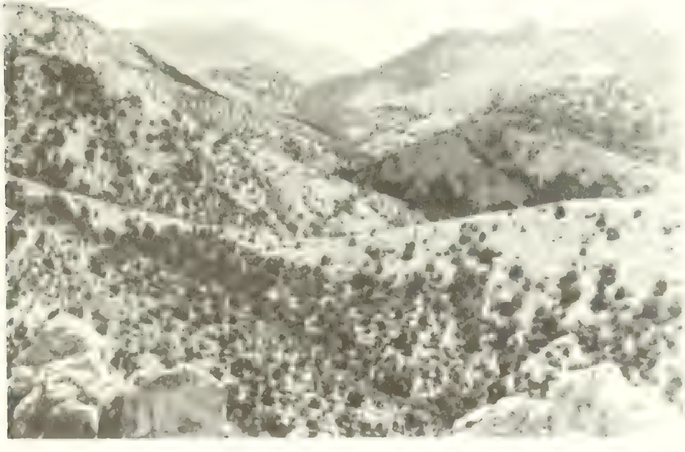

Figure 16. Desert shrub-steppe. Central Peloncillo RNA. (File photo, BLM, Las Cruces.)

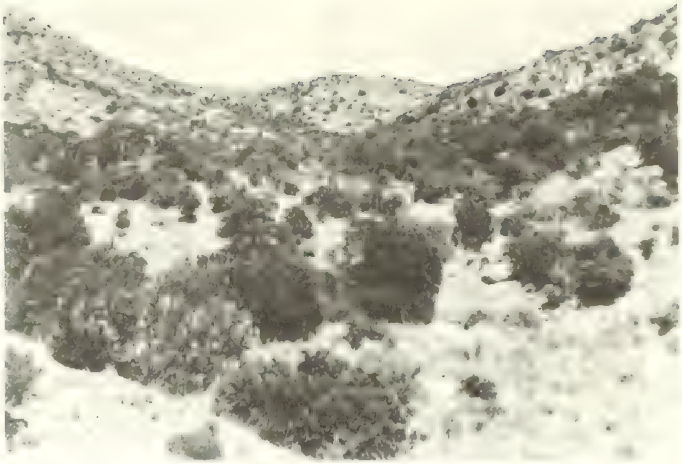

Figure 17. Pinyon-juniper woodland. Central Peloncillo RNA. (File photo, BLM, Las Cruces.)

Rock land—80% or more rhyolite bedrock—has lichens, small cacti, annuals, and infrequent perennial grasses and crevice plants, with an occasional low pinyon. This vegetation type is colorful and abundant.

Studying flora rather than vegetation, Todsen (1980) found many interesting species in the RNA, including *Brickellia simplex*, *Plummera ambigens*, *Echinocereus pectinatus* var. *rigidissimus*, *Ferocactus wislizeni*, *Mammillaria macdougalii*, and *Cheilanthes pringlei*. He lists about 250 taxa of vascular plants other than grasses for the area. Species and vegetation types are frequently near their northern or eastern limits here, and Todsen found several plants new to New Mexico in the RNA.

Küchler (1975) maps the higher Peloncillos as oak-juniper woodland (Type 31) and lower elevations of the area as grama-tobosa shrubsteppe (Type 58). Donart et al. (1978) map the area as the brush-juniper series of mountain shrub (Type MS–2). While not wrong, these broad categories fail to reflect the intricate mosaic of vegetation and its largely Madrean relationships.

Vegetation of the area is recovering from a long period of serious overuse by goats and cattle. Only a few inaccessible ledges escaped abuse. High erodibility slows revegetation.

Animals

For an area presumed to be low in productivity due to denudation, Central Peloncillo RNA displays a diversity and abundance of wildlife. This diversity received attention when natural-area efforts in New Mexico were young: in a 1967 meeting this Black Mountain area was described as uniquely providing habitat for four desert species—coati, Coues' white-tailed deer, a heavy population of javelina, and band-tailed pigeons, and possibly also whiskered owls (USDI BLM 1967).

Mammals characteristic of the desert mountains identified within the RNA include Coues' white-tailed deer, javelina, coati, ringtail, hog-nosed skunk, hooded skunk, and desert shrew. Other, wider-ranging species in the RNA include mule deer, coyote, gray fox, mountain lion, bobcat, black bear, striped skunk, cottontail, blacktail jackrabbit, rock squirrel, cliff chipmunk, whitethroated woodrat, yellow-nosed cotton rat, brush mouse, rock pocket mouse, pocket gopher, and bats.

Reptiles and amphibians have been studied by Jones (1976), Bogert (1977), and Dixon (1978). Lizards reported in the RNA include *Cnemidophorus sonorae, Crotaphytus collaris, Gerrhonotus kingi, Holbrookia maculata, Phrynosma cornutum, P. douglassi, Sceloporus clarki, S. jarrovi, S. magister, S. poinsetti, S. undulatus, S. virgatus, Urosaurus ornatus*, and *Uta stansburiana*, and a record of the Gila monster (*Heloderma suspectum*) in or near the RNA. Snakes reported include *Crotalus atrox, C. lepidus, C. molossus, Elaphe triaspis, Hypsiglena torquata, Masticophis bilineatus, Pituophis melanoleucus, Salvadora grahamiae*, and *Thamnophis cryptopsis*. Mud turtle (*Kinosternon* sp.) and desert tortoise (*Gopherus agassizi*) are recorded by Dr. Scholes. *Bufo alvarius, B. punctatus*, and *Hyla arenicola* are the identified amphibians. Studies of birds have been intensive, with about 150 species recorded in the RNA including 6 ducks, 14 raptors, 5 doves, 4 goatsuckers, 7 hummingbirds (including Lucifer), 8 woodpeckers, 5 corvids, 6 parids, 6 wrens, 5 mimids, 11 warblers, 7 icterids, and 25 fringillids. Counts since Christmas 1973 have been published, and a permanent transect for detailed observation has been maintained since 1981.

Archaeology

Site numbers have been assigned by the Laboratory of Anthropology (Museum of New Mexico, Santa Fe) to four sites recorded by A. Hayes in a 1980 survey.

Intrusions and Threats

The area was grazed by cattle from about 1880–1900, then also by goats for two or three decades. Cattle grazing continued legally until 1973, when 56 cattle year-long were allowed on the federal 2,511 acres (448 "forage acres")—a very high level of demand on this desert grassland. Effects of grazing will remain for decades or centuries, since soil was lost from denuded slopes.

Two-track roads crossed the mountains, connecting Maverick Canyon on the east with Skull and Post Office canyons on the west and with a canyon that drains south past Mt. Baldy. On steep slopes these roads are deeply eroded and unusable, even were vehicles permitted.

The 1918 topographic map shows two buildings in Maverick Canyon, and there have been others on the area from time to time. Several small dams and stock ponds have been built, of which two are maintained. The depredations of non-native feral swine, often visible in woodland, may be regarded as a continuing intrusion.

Research

Bioresearch Ranch has sponsored a research program in the RNA probably unmatched in southwestern New Mexico, including birdbanding, insect collections, and, prominently, the work of W. H. Moir (1979, 1980, and other reports) on vegetation, soils, and hill-slope processes. The Bureau of Land Management, New Mexico Department of Game and Fish, and the New Mexico Heritage Program have sponsored censuses in the RNA, such as Dixon's (1980), Todsen's (1980), and a 1977 deer census.

Maps

Topographic: USDI—Geological Survey 1:62,500 series, Animas Peak Quadrangle, 1918. Resurveyed around 1977 but not yet published. Vegetation: part of the RNA is included in Moir (1979). Soils: Cox (1973) uses a single mapping unit for the RNA. For aerial photography see Cox (1973).

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CHUPADERA RESEARCH NATURAL AREA

Desert shrubsteppe dominates this mountainous, 5,389-acre wilderness and natural area. The highest, rocky hills rise 1,420 feet above the low edge of the area along Interstate 25. Most of the area is covered by gravelly terraces and bajadas that now support only creosotebush and a thin grass cover. Higher slopes and valleys support a variety of shrubs and grasses. Wildlife is limited by lack of permanent water, but includes several desert-adapted species.

Administration

Refuge Manager
Bosque del Apache National Wildlife Refuge
P.O. Box 1246
Socorro, NM 87801 (505) 835–1828

Chupadera is one of five natural areas on the Bosque del Apache Refuge, a 57,191-acre unit of the National Wildlife Refuge System administered by the Fish and Wildlife Service, U.S. Department of the Interior. The Refuge was established in 1939 on land purchased by the federal government in 1936. Chupadera was designated as a 5,289-acre (2,140-hectare) Research Natural Area December 7, 1972. (A previous proposal would have established a 320-acre natural area centered a mile east of Chupadera Peak. This is within the larger area actually designated.) In 1975 the Congress declared the same area a wilderness.

Entrance and exit by Refuge roads is allowed only during daylight. Hunting of deer, dove, quail, and rabbits is allowed in season. Mineral entry (including prospecting) is prohibited, as are vehicles and livestock. The whole area is fenced except for a few west-side crags regarded as impassable to livestock.

Location and Access

Chupadera Research Natural Area is in Socorro County at lat. 33°50′N., long. 106°56′30″ W. (fig. 18). Part of a land grant, the area was not surveyed by the United States but would be in T. 5 S., R.1 W., and T. 6 S., R. 1 W. The eastern boundary is the Interstate 25 right-of-way, and other boundaries are the north, west, and south boundaries of Bosque del Apache Refuge.

Chupadera is 90 miles south of Albuquerque (14 south of Socorro) and 126 miles north of Las Cruces (or 54 north of Truth or Consequences). For ingress to the natural area from Refuge roads (open only during daylight hours), turn off I–25 onto N.M. 1 at San Antonio from the north or San Marcial from the south and follow Refuge signs. A convenient route is by a road that heads northwest from N.M. 1, 2 miles north of Refuge headquarters. Passage on foot under the interstate highway is through a large culvert.

Accommodations are available in Socorro.

Climate

Climate of creosotebush areas south of Socorro, such as Chupadera, is discussed by Gardner (1951), and climate of the county is discussed by Houghton (in Maker et al. 1972). Data from Refuge headquarters, 2.6 miles east of and 300 feet lower than the lowest part of Chupadera, are given above under Apache Camp RNA.

Physiography, Geology, Soils

The area is in the Mexican Highlands section of the Basin and Range Province (Fenneman 1931). The Chupadera Mountains, on whose eastern slopes and foothills the RNA is located, are a northeast-southwest trending range of which Chupadera Peak, at the west edge of the RNA, is the highest, 6,273-foot (1,912 m.) peak, 1,420 feet above the eastern boundary at 4,853 feet (1,479 m.). This southern section of the Chupadera Mountains is also known as Coyote Hills. They appear craggy; 50- to 100-foot cliffs are common. This is a typical fault-block range, part of the Lemitar-Socorro-Chupadera chain formed by deformation in late Tertiary or in Quaternary time (Denny 1940). Deformation continues; the Chupaderas are at the southern end of a 45-mile line in which the rate of uplift (north of Socorro) is 5 mm. per year (Reilinger and Oliver 1976).

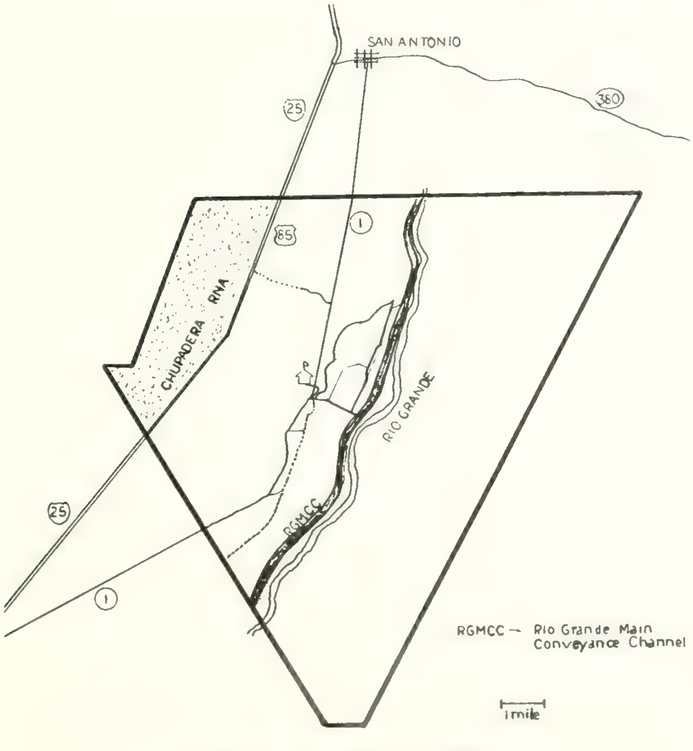

Figure 18. Chupadera RNA.

The core of the range is of igneous and metamorphic Precambrian rock, exposed at the west edge of the natural area where coarsely crystalline granite and gneiss intrude gray muscovite-hornblende schist (Bachman and Stotelmeyer 1967, Eggleston 1982, Kent 1982). Overlying are about 30 feet of Mississippian Calosa Formation and 200 feet of Pennsylvanian Madera Formation—mostly a cliff-forming limestone—each with small areas of outcrop (Kottlowski 1960). Armstrong (1959) reports crinoids, brachiopods, and mollusks in the Calosa Formation here, and Kottlowski (1960) records brachiopods, fusulinids, and horn corals from the Pennsylvanian. Most of the mountain area within the RNA is covered by Tertiary volcanics of the Datil formation, described by Dane and Bachman (1965) as welded and crystal tuffs, flows, and breccias.

Below the steep mountain slopes are 4–8% easterly slopes cut by steep-sided washes; these bajadas cover most of the natural area. In the central part some poorly consolidated strata of the Tertiary Santa Fe Group are exposed, dipping 65° west (Bachman and Stotelmeyer 1967). Quaternary terrace gravels top the Tertiary formation over most of the bajadas. Ruhe (1967) discusses the pediments that shape these landforms along the Rio Grande.

Soils in the area are thermic-aridic, of rocky or gravelly texture. On the bajadas are several members of the Nickel-Canutio-Rough Broken Land association, typically with a gravelly caliche layer a foot or two deep (Maker et al. 1972)—or sometimes, it appears, much closer to the surface. This association belongs to Torrifluvents-Calciorthids-Torriorthents great groups. On the mountains are soils of the Rock Land-Lehmans-Lozier association, largely (in our area) Rock Land, a miscellany of shallow soils and rock outcrops. This association is classified as Rockland-Haplargids.

Vegetation

The bajadas are sparsely covered by creosotebush (*Larrea tridentata*), with bush muhly (*Muhlenbergia porteri*) under many of the shrubs (fig. 19). Other necessarily-tough survivors on these gravelly slopes are black grama (*Bouteloua eriopoda*), three-awns (*Aristida glauca* and *A. longiseta*), fluffgrass (*Erioneuron pulchellum*), burro grass (*Scleropogon brevifolius*), tobosa (*Hilaria mutica*), and snakeweed (*Gutierrezia sarothrae*). But much of the gravel surface is bare.

On the mountains the vegetation is desert shrubsteppe, of greatly varying density depending on the character of the erosion surfaces. Shrubs include one-seed juniper (*Juniperus monosperma*), sotol (*Dasylirion*), sacahuista (*Nolina*), yuccas (*Yucca baccata* and *Y. glauca*), four-wing saltbush (*Atriplex canescens*), sumacs (*Rhus microphylla* and *R. aromatica* var. *trilobata*), feather plume (*Dalea formosa*), snakeweed, and low sage (*Artemisia arbuscula*). Grasses include galleta (*Hilaria jamesii*), gramas (*Bouteloua curtipendula* and *B. gracilis*), dropseeds

(*Sporobolus* spp.), slim tridens (*Tridens muticus*), hairy tridens (*Erioneuron pilosum*), and bluestems (especially *Bothriochloa barbinodis*) (fig. 20). Creosotebush goes high on the hills, at least to 5,400 feet elevation, where it sometimes grows in quite dense grass stands (fig. 19); but in such situations many creosotebushes are dying.

Ecology of creosotebush stands on the Rio Grande bajadas is discussed by Gardner (1951), Yang (1961), Dick-Peddie (1975), Welsh and Beck (1976), and Stein and Ludwig (1979).

Küchler (1975) maps the potential natural vegetation as creosotebush-tarbush (Type 44), but most members of that association are lacking. One hopes that this is potentially his Type 58, grama-tobosa shrubsteppe.

Animals

Mule deer, coyote, black-tailed jackrabbit, and burrowing rodents such as kangaroo rats and ground squirrels are in evidence. Mountain lion, desert cottontail, woodrat, pocket gopher, and several mouse species are likely. Occasional pronghorns are recorded here (USDI—Fish and Wildlife Serv. 1970).

Several lizard and snake and many bird species are common; among the birds are Gambel's quail and mourning dove. There are nest sites for hawks and owls.

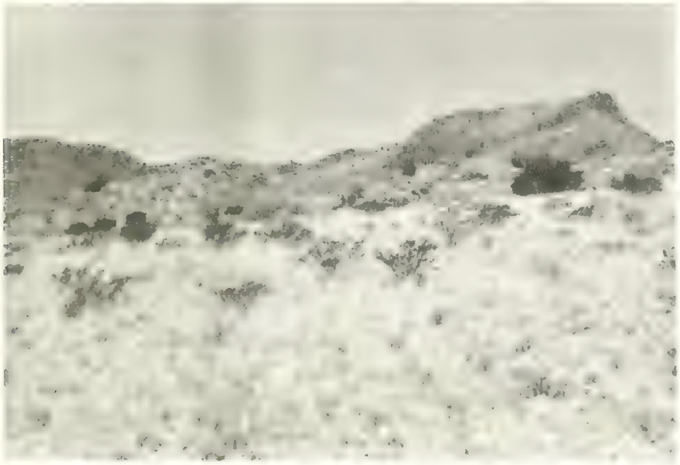

Figure 19. Creosotebush and grass. Chupadera RNA.

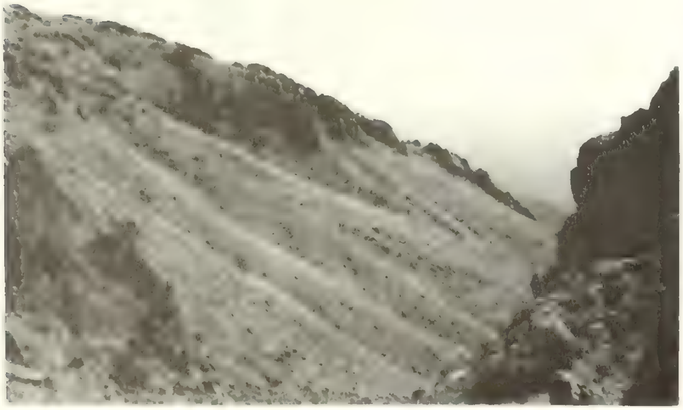

Figure 20. Slopes of the Chupadera Mountains.

Intrusions and Threats

The principal intrusions are noise and lights from traffic on Interstate 25, which runs the length of this narrow RNA. An abandoned bladed road from the east leads up to a shallow rock quarry at the south foot of "Cone RG." The quarry has mostly grown over, but much of the road, though unused for at least 8 years, is bare and conspicuous. There are a 7-foot pit and a 6-foot shaft in the Madera limestone outcrop; apparently these explored a thin coating of manganese mineral.

Research

Only geologic research is known; see Eggleston (1982) and Kent (1982).

Maps

Topographic: USDI—Geological Survey 1:24,000 series, Indian Well Wilderness Quadrangle, 1981. Geology: Bachman and Stotelmeyer (1967), Eggleston (1982), Kent (1982), Kottlowski (1960). Soils: Maker et al. (1972).

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GALLINAS RESEARCH NATURAL AREA

A 345-foot-deep river canyon cuts the rolling grassland and conifer woodland of this 385-acre wildlife (and livestock) area. The Dakota Sandstone is well exposed along canyon rims in this fine exemplar of the Las Vegas Plateau. A rich array of grasses grows in and near the canyons.

Administration

Refuge Manager
Las Vegas National Wildlife Refuge
P.O. Box 1070
Las Vegas, NM 87701 (505) 425–3581

The 9,450-acre Refuge is a unit of the National Wildlife Refuge System administered by the Fish and Wildlife Service, U.S. Department of the Interior. The Refuge was established on purchased land in 1966 to restore wildlife habitat. The 385-acre (156-hectare) RNA was designated August 17, 1973.

The Research Natural Area is not posted or fenced as such. A permit is required to visit the area, as it is for other "backcountry" parts of the Refuge. Hunting is prohibited.

Cattle are grazed in the RNA under permit to local ranchers. The east section was grazed for 5 weeks in September–October 1981, but rested in 1980 and 1982. The west section has not been grazed in 1980–1982.

Although 0.2 miles of the bottom of Gallinas Canyon are included in the Refuge and in the RNA, they are not fenced or posted and are not managed by the Refuge Manager. Maps given to the public (as in USDI—Fish Wildlife Serv. 1980) exclude the canyon bottom from the Refuge. That area is "overgrazed annually by livestock" according to the Refuge Manager in 1982.

Gallinas and Vegosa RNA's could well be considered as one, though separated by 0.5 miles.

Location and Access

Gallinas Research Natural Area is in San Miguel County, centered at lat. 35°30′20″ N., long. 105°11′00″ W. (fig. 21). The area was not included in the general land survey, but would be mostly in T. 15 N., R. 16 E., with the east edge in T. 15 N., R. 17 E. The north boundary of the RNA appears to lie along lat. 35°30′41″ N., the east along long. 105°10′36″ W., the west along long. 105°11′41″ W., and the south, which has 3 segments, is the south Refuge boundary between those longitudes.

Las Vegas National Wildlife Refuge is 5 miles southeast of Las Vegas. From downtown Las Vegas or from the N.M. 65–104 interchange of Interstate 25, drive east on N.M. 65–104 about 1.5 miles, turn south on N.M. 281 and follow its turns (east and then south again) for 4.5 miles to Refuge headquarters. There a permit to enter the RNA may be sought. Gallinas RNA is in the south end of the Refuge. From headquarters the main road goes south 2.4 miles, then west and northwest 1.2 miles; there turn south on a branch road for 0.7 miles, almost to the RNA.

The nearest accommodations are in Las Vegas. Camping is permitted at McAllister Lake, 0.6 miles northeast of the RNA, in an area managed by the New Mexico Department of Game and Fish.

Climate

Las Vegas and the Refuge are in a cool, moist area with mean temperature 50°F (10°C) and average annual precipitation of 16 inches (400 mm.). The record low is −31°F (−35°C), the high 100°F (38°C). The growing season is about 160 days. Climate of the area is discussed by Griggs and Hendrickson (1951) and by Hilley et al. (1981). Monthly averages from Las Vegas (Station 4,850), 7 miles northwest of the RNA are shown in figure 22.

Physiography, Geology, Soils

Gallinas Research Natural Area is near the western limit of the Great Plains; the Sangre de Cristo Mountains are 4 miles to the west. And it is at the southwestern limit of the Las Vegas Plateau, which includes much of New Mexico east of the Sangre de Cristos (Fenneman 1931). Like the Plateau in general, the RNA is a peneplain on Dakota Sandstone deeply cut by stream action. Unlike nearly all the Plateau, the Las Vegas Refuge drains to the Pecos River (and thence to the Rio Grande) rather than the Canadian (thence to the Arkansas and the Mississippi). Lee (1903) discusses canyons of the Las Vegas Plateau.

The Gallinas River flows through the southwest edge of the natural area in a 345-foot-deep canyon. The area is further cut by a side canyon of the Gallinas that begins at the north edge of the natural area and empties southward, reaching a depth of 310 feet in its half-mile crossing of the area. With the aid of a little fencing near its origin this canyon effectively divides the area into two sections.

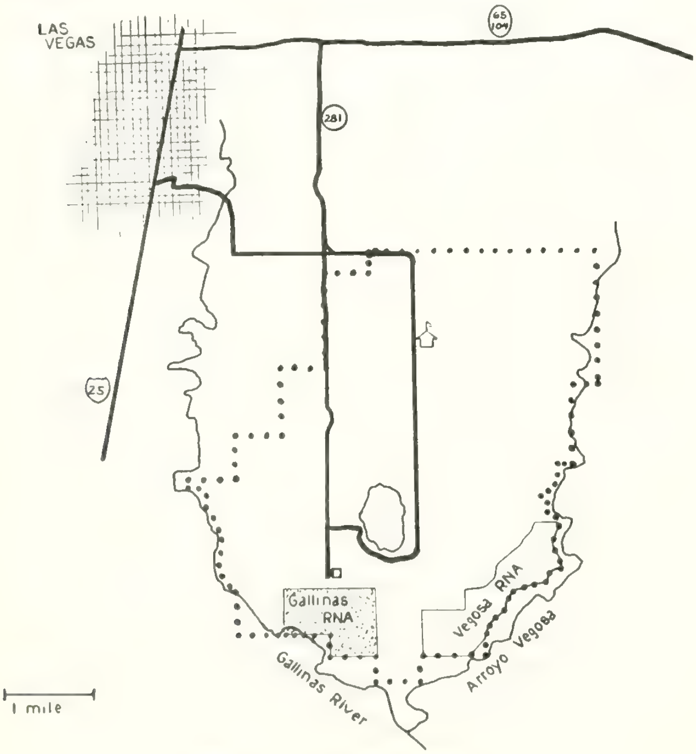

Figure 21. Gallinas RNA.

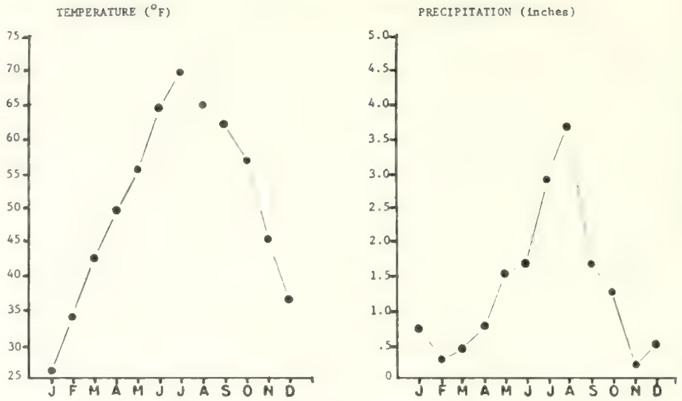

Figure 22. Climate of Gallinas RNA.

Eastern and northwestern parts of the RNA, comprising about 320 acres, are uplands with slopes less than 6%, mostly less than 3%. About 65 acres are in the canyons: 60 acres with slopes averaging more than 60% and 5 acres of flat canyon bottom. Edges of the canyons are abrupt; the top 15 feet or so are generally vertical. Elevations in the RNA range from 6,058 to 6,475 feet (1,847 to 1,974 m.).

The caprock, which may be more than 200 feet thick here, is Dakota Sandstone, of Late Cretaceous age. It is abundantly exposed along the 1.45 miles of canyon edge in the RNA. Griggs and Hendrickson (1951) describe the formation as fine-grained, highly quartzitic sandstone, containing pebbles of quartz and of chalcedonic silica. Several small towers on the lip of Gallinas Canyon show relatively fresh, white to buff surfaces of the sandstone. Older surfaces are dark red or brown. Exposed in canyons below the Dakota is, presumably, the Morrison Formation (Jurassic), here taken to include the Upper Cretaceous Purgatoire Formation, if present; it includes various sandstones and shales.

Further geological information is given by Bejnar and Lessard (1976), Jacka and Brand (1972), and Lessard and Bejnar (1976).

Soils are mollisols of the great groups Argiustolls and Paleustolls, produced by a mesic soil regime in a ustic moisture regime (Hilley et al. 1981). Five mapping units are in the RNA but three of them, on flat to rolling uplands, are mainly Partri loam, typically with the surface layer about 4 inches of dark silt loam. On the east side of the RNA Tricon loam, a Petrocalcic Paleustoll, is mixed with Partri loam, and there are also small areas of Bernal and perhaps of Carnero soils. Nearer canyon edges, covering almost half the RNA, is Bernal loam, with a brown surface layer about 6 inches thick and the parental sandstone less than 2 feet down. Canyons are mapped as "steep Tuloso-Rock Outcrop-Sombordoro Association," comprising stony sandy loam and rock.

Vegetation

Uplands farthest from canyon edges are grasslands; closer to the canyons, including an area of 60 or 70 acres east of the side canyon, is pinyon-juniper woodland grading into juniper-oak savanna (fig. 23). Along the edges are ponderosa pines with Rocky Mountain juniper. Canyon sides are mainly covered with shrubs such as Apache plume (*Fallugia paradoxa*), but also grasses and scattered conifers (fig. 24). Grasses and sedges dominate the narrow canyon bottoms.

Grasses on wetter sites, including upper reaches of the side canyon and near conifers, are a rich mix of mid- and tall-grasses: Indian grass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), silver bluestem (*Bothriochloa saccharoides*), sideoats grama (*Bouteloua curtipendula*), and, here at their northern known limits, plains lovegrass (*Eragrostis intermedia*) and bullgrass (*Muhlenbergia emersleyi*).

Hilltop sites and northern parts of the RNA are more heavily grazed and have a less impressive variety of plants, mainly gramas (*Bouteloua gracilis* and *B. curtipendula*), wolftail (*Lycurus phleoides*), sand dropseed (*Sporobolus cryptandrus*), windmillgrass (*Chloris verticillata*), ring muhly (*Muhlenbergia torreyi*), fringed sage (*Artemisia frigida*), and soapweed (*Yucca glauca*). Grassland is apparently being invaded by juniper (*Juniperus monosperma* and *J. scopulorum*) and oak (*Quercus undulata*).

Least muhly (*Muhlenbergia minutissima*) is frequent in crevices on level rock surfaces, and spleenwort (*Asplenium septentrionale*) is common in crevices on cliff faces.

Although vegetation is listed as potentially grama-buffalo grass (Küchler's Type 65) in the Directory of Research Natural Areas (U.S.—National Science Foundation 1977), that seems unlikely except possibly for a small area in the northeast of the RNA. Küchler (1975) himself maps Juniper-Pinyon Woodland (Type 23) and Grama-Galleta Steppe (Type 73). Hilley et al. (1981) suggest mainly blue and sideoats grama, galleta, and western wheatgrass for the Partri and Tricon soils; and although there is not much galleta or wheatgrass in evidence now, this seems a likely prognosis if livestock grazing continues light.

Animals

Mule deer, Nuttall's cottontail, black-tailed jackrabbit, coyote, and bobcat are the common larger mammals. Also likely are desert shrew, gray fox, raccoon, long-tailed weasel, mink, striped skunk, mountain lion, and many rodent species.

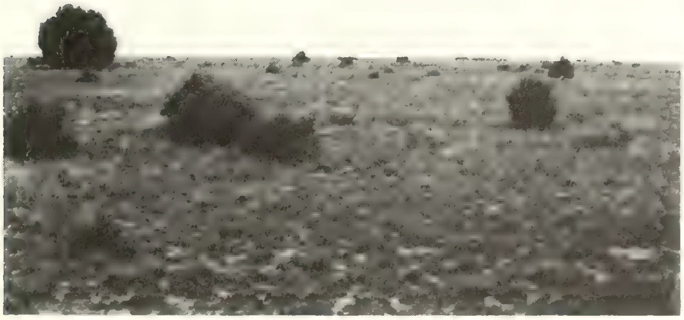

Figure 23. Juniper savanna. Gallinas RNA.

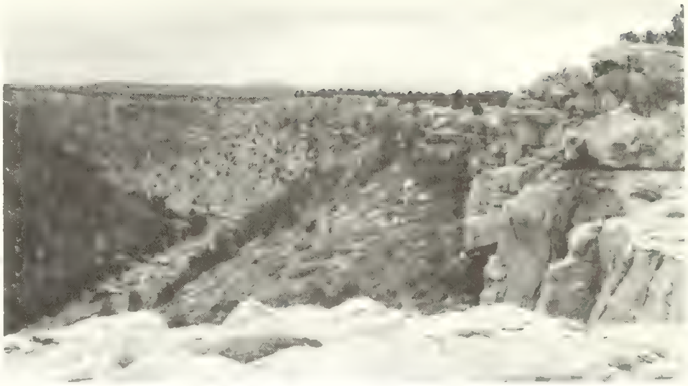

Figure 24. Canyon of the Gallinas River within Gallinas RNA.

Red-tailed hawk, golden eagle, prairie falcon, kestrel, scaled quail, ring-necked pheasant, turkey, long-billed curlew, mourning dove, nighthawk, white-throated swift, black-chinned and broad-tailed hummingbirds, red-shafted flicker, Lewis' woodpecker, and 37 species of passerine birds are listed as "common" on the Refuge and might well be in Gallinas RNA (USDI—Fish Wildlife Serv. 1984).

Intrusions and Threats

A home (the state game warden's) is 200 feet north of the RNA; a small water impoundment there reaches the edge of the natural area. An even smaller, usually dry impoundment is mapped near the eastern edge of the RNA. The uplands are grazed by cattle but apparently only lightly; damage to vegetation is probably mainly from pre-Refuge days.

The principal intrusion is that a fine stretch of the Gallinas River within the Research Natural Area has been left "outside" for all practical purposes, and is used for a private ranching operation.

Research

None is known.

Maps

Topographic: U.S. Geological Survey 1:24,000 series, Las Vegas Quadrangle, 1963. Geology: Griggs and Hendrickson (1951). Soils: Hilley et al. (1981). Aerial photography: see Hilley et al. (1981).

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GILA RIVER RESEARCH NATURAL AREA

The Gila River here winds through the Big Burro Mountains in a 600-foot-deep canyon, its sloping walls interrupted by side canyons. The natural area was established mainly to protect habitat for hawks, falcons, herons, and songbirds here at the edges of their distributions. It may be more important for protection of native fish species. Riparian woodland is now represented in the area by a sparse line of cottonwoods, sycamores, ashes, and hackberries, floods having destroyed many trees in recent years. Most of the 402 acres are desert shrubland.

Administration

Supervisor
Gila National Forest
2610 N. Silver Street
Silver City, NM 88061 (505) 388–1986
and Director
Rocky Mountain Forest and Range Experiment Station
240 West Prospect
Ft. Collins, CO 80526 (303) 221–4390

The co-administrators represent national forest and research branches of the Forest Service, U.S. Department of Agriculture. On-the-ground management is by the District Ranger, Silver City District, Gila National Forest, also in Silver City.

These lands in the Big Burro Mountains were added (from public domain lands) to the Gila National Forest in 1907 and 1909. After several years of proposals Gila River Research Natural Area was designated June 23, 1972, mainly to protect riparian habitat for rare or endangered bird species. Its area is 402 acres (163 hectares). It is intended as a natural control area for the Gila River Bird Habitat Management Unit immediately upstream; there (but not in the RNA) manipulation of vegetation to improve habitat was planned (USDA—Forest Serv., 1972). It was recognized that the Research Natural Area was sub-optimal for riparian habitat, but the area was chosen because it was relatively pristine and in deference to possible mining claims near better cottonwood stands upstream (USDA—Forest Serv. 1969).

The RNA is open to hunting and grazing. It is closed to off-road vehicles, and the road-end is blocked at the head of the canyon, 2.5 miles upstream from the RNA, but this closure has continued to be violated at least occasionally and presents an enforcement problem. The natural area is not fenced or posted. Withdrawal from mineral entry was proposed in the Federal Register in 1970 but was not made final until September 2, 1975, due to controversy; but the difficulty mainly concerned upstream areas also proposed for withdrawal rather than the RNA itself. The Forest Service has tried to defend water rights to protect in-stream flow in this part of the Gila River (USDA—Forest Serv. 1972).

Location and Access

Gila River Research Natural Area in Grant County, centered at lat. 32°47′00″ N., long. 108°36′45″ W. (fig. 25). It is in T. 17 S., R. 17 W., in sec. 32 (E1/2 of the E1/2) and sec. 33 (NW1/4, and W1/2 of the SW1/4).

The RNA is 12 miles south of Cliff and 30 road miles west of Silver City. From Socorro the route via Interstate 25, N.M. 90, and U.S. 180 is 199 miles, or about 15 miles shorter than that via U.S. 60, N.M. 12, and U.S. 180. From Las Cruces the distance by Interstate 10 and U.S. 180 is 149 miles. Turn south from U.S. 180 on Forest Road 809, 1.2 miles west of the N.M. 211 junction (= 4 miles southeast of Cliff). Drive south on 809 to its end. Thence walk, float, or paddle downstream for about 2.5 miles to the RNA. Wading the river saves rockclambering at two or three points. Rough National Forest roads suitable for high-clearance vehicles approach within 1.5 miles of the RNA from both east (Wild Horse Mesa) and west (Telegraph Mountain).

Accommodations are in Silver City, 30 miles east, and in Pleasanton and Glenwood, 30 and 34 miles northwest. There is a campground at Bill Evans Lake (see figure 25), and camping is allowed on these National Forest lands.

Climate

This is a semi-arid area, with average annual precipitation about 12 inches (300 mm.) and mean temperature 59°F (15°C). Half the annual precipitation falls from July to September in brief but intense thundershowers; a storm that brings 1.6 inches of rain within a single 24-hour period is expected (on average) once in 2 years. Climate of the area is discussed by Henry (1981), Maker et al. (1971), and in some detail by Trauger (1972). Monthly averages from data at Red Rock (Station 7340), 10 miles downstream and 100 feet lower than Gila River RNA, are graphed in figure 26.

Physiography, Geology, Soils

The Big Burro Mountains, here deeply cut by the Gila River, are a southwestward extension of the Gila highlands (at the edge of the Colorado Plateau) into the Basin and Range Province (Fenneman 1931). Burro Peak, on the Continental Divide, is highest in the range at 8,035 feet elevation. The Gila drains those highlands and flows south and then across Arizona to the Colorado River near Yuma. Use of river water for irrigation is heavy and most of this long channel is dry most of the time, but flow is perennial through the Middle Gila Box in which the RNA is located.

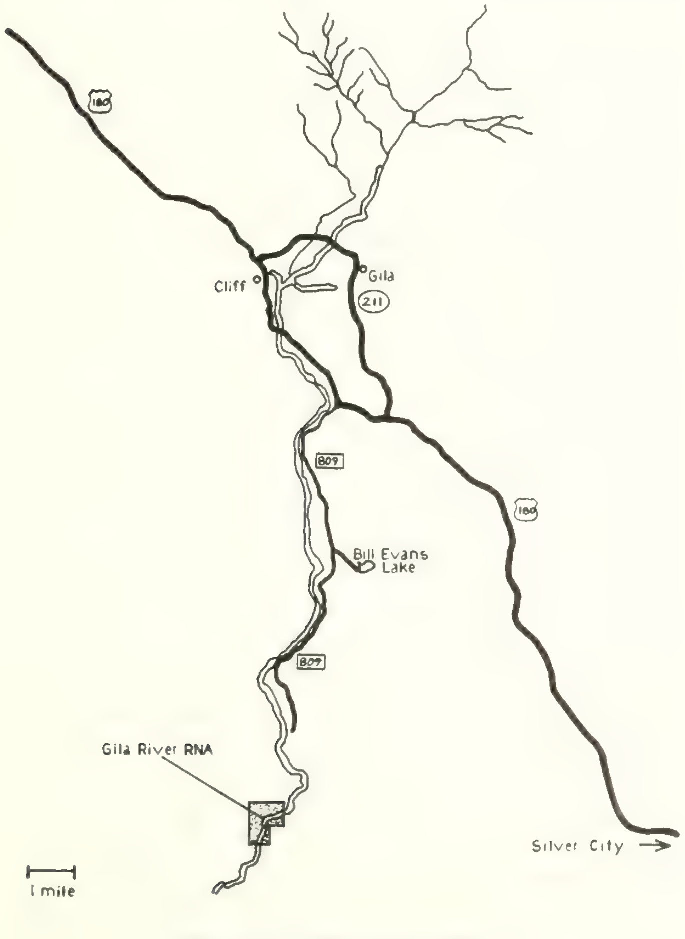

Figure 25. Gila River RNA.

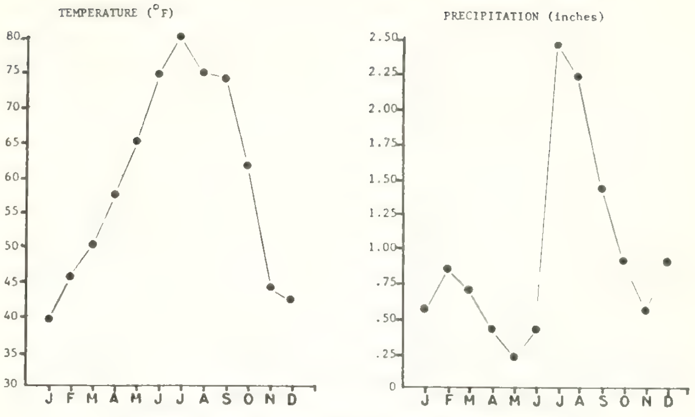

Figure 26. Climate of Gila River RNA.

This canyon, scarcely a box, has slopes characteristic of the Big Burros: 20–50%, with only occasional steeper pitches and small cliffs. High points of the RNA (in both north and south ends) are at 4,880 feet (1,487 m.) elevation; the low point, where the river leaves after dropping 35 feet in the RNA, is at 4,250 feet (1,295 m).

Average flow of the Gila above Red Rock, 6 miles below the natural area, is 194 cubic feet per second (*cfs*), reaching a high of 402 cfs in March and a low of 66 cfs in June (Trauger 1972). The least flow recorded near Red Rock from 1905 through 1981 was 2.2 cfs and the greatest, in 1978, was 48,800 cfs (USDI-Geol. Surv. 1982). These readings are probably close to those that would be measured at the RNA itself.

Five ephemeral streams enter the Gila in its approximately 1.5-mile course through the RNA. We list them because of confused name-reversals on some maps: from the right (or west) side, proceeding downstream, (1) Faucet Canyon, (2) an unnamed stream in the center of the RNA, and (3) Pyrite Canyon near the southern border of the RNA; from the left (east or south) side, (1) an unnamed canyon at the northeast boundary of the RNA that drains Ira Ridge and, near it (2) Wild Horse Canyon. A stream from St. Peter's Rock enters just above the RNA and Buzzard Canyon enters 500 feet below it.

The Big Burro Mountains consist mainly of Precambrian granite and associated rocks—such as a quartz diorite gneiss—of the Burro Mountain batholith (Gillerman 1964). These Precambrian strata are mapped for the southern 270 acres of the RNA by Trauger (1972) but only for a southeastern 60 acres by Gillerman (1964). Both authors show Cretaceous strata in the southwest part of the RNA; for Trauger it is the Beartooth Quartzite (with the Colorado Formation 0.5 miles farther west); for Gillerman it is shale and sandstones of the Colorado Formation (with Beartooth Quartzite 0.2 miles farther west). USDA—Forest Service (1969) lists both formations. Both authors map the northern part of the natural area as Datil Formation, a complex of Tertiary rhyolite, flow breccia, tuff, ash, and ashflow welded tuffs formed during a cycle of eruptions in Oligocene time. According to Trauger the Datil-Precambrian border is the east-west Wild Horse Fault, along which the river flows west for half a mile. Hewitt (1959) has also done detailed geological mapping of this area, which is the Red Rock Mining District.

Soils of the Research Natural Area are aridic-lithic Haplustolls and Argiustolls of the Rockland-Luzena-Santana Association (Maker et al. 1971), mostly stony or cobbly loams. In the narrow floodplain and on alluvial fans just above it are fine-loamy San Mateo and Shanta soils, which are ustic Torrifluvents and cumulic Haplustolls.

Vegetation

Desert shrubs cover about 340 of the RNA's 400 acres, although a very thin scattering of one-seed junipers (*Juniperus monosperma* in the wide sense) and pinyon (*Pinus edulis* var. *fallax* and var. *edulis*), mostly on north slopes, led to classification of 125 of the 340 acres as pinyon-juniper woodland (USDA—Forest Serv. 1969) (fig. 27). Ten acres or so are really dominated by conifer woodland.

Prominent on slopes of the desert shrub steppe are soapweeds (*Yucca* spp.), sotol (*Dasylirion wheeleri*), shrub live oak (*Quercus turbinella*), mesquite (*Prosopis*), whitethorn (*Acacia constricta*), wait-a-bit (*Mimosa biuncifera*), ocotillo (*Fouquieria splendens*), prickly pear (*Opuntia engelmannii* and others), desert buckthorn (*Ceanothus greggii*), oreganillo (*Aloysia wrightii*), wolfberry (*Lycium pallidum*), turpentine bush (*Ericameria laricifolia*), and snakeweed (*Gutierrezia sarothrae*). The many grass species include gramas (*Bouteloua* spp.), sprangletop (*Leptochloa dubia*), tridens (*Tridens muticus*), and threeawns (*Aristida orcuttiana* and others). In dry washes are added to this list alligator juniper (*Juniperus deppeana*), burrobrush (*Hymenoclea monogyra*), rock sage (*Salvia pinguifolia*), hedge nettle (*Stachys coccinea*), *Baccharis* species, and large grasses including bullgrass (*Muhlenbergia emersleyi*), deergrass (*M. rigens*), and bristlegrass (*Setaria macrostachya*). The only large alluvial fan of the natural area, formed by wash from Faucet Canyon and the stream next south, supports a dense mesquite grove with patches of burroweed (*Isocoma tenuisecta*).

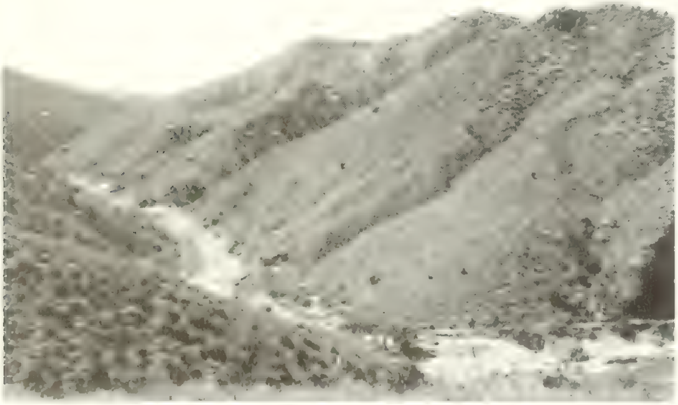

Figure 27. The southern half of Gila River RNA. Old road in lower right.

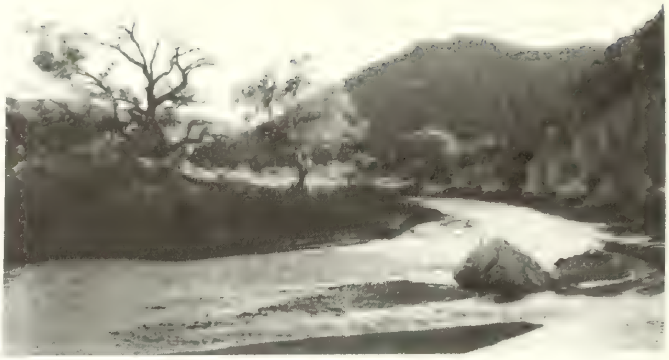

Figure 28. Sparse riparian woodland of Gila River RNA.

Riparian woodland, protection of which is the RNA's purpose, is in short supply; apparently there is much less than when the area was surveyed in 1969 (USDA—Forest Serv. 1969) (fig. 28). Flood waters have scoured much of the floodplain in recent years and left trash 15 feet high in trees that survived. Walnut and boxelder, listed in 1969, were not found in 1982. Trees in the 1.5 miles of main canyon now include only about 4 cottonwoods (*Populus fremontii*), 1 ash (*Fraxinus velutina*), and 20 or 30 sycamores (*Platanus wrightii*); also many hackberries (*Celtis reticulata*) but most of these are in one grove opposite Wild Horse Canyon. Of the side canyons, Pyrite Canyon has hackberries and large junipers. Faucet Canyon has a cottonwood and hackberries, and Wild Horse Canyon has several sycamores, an ash, and hackberries. (These details—although approximate—may be useful in some future decade if the RNA survives.)

A few stretches of riverbank, especially opposite Wild Horse Canyon, are thickly lined with 8-foot seepwillows (*Baccharis glutinosa*). Mudflats in October 1982 were covered with cupgrass (*Eriochloa gracilis*) and water speedwell (*Veronica anagallis-aquatica*). Sixweeks grama (*Bouteloua barbata*) grows on sand by the river. The desert shrubland best fits Küchler's Grama-Tobosa shrubsteppe (Type 58). The species-list above combines several distinct associations that form a mosaic in the RNA.

Henry (1981) discusses riparian vegetation of the Big Burro Mountains, including biogeographical aspects. Lowe (1964) describes both riparian and desert shrub vegetation of the sort found here.

Animals

Among those discussing the importance to a variety of wildlife of this part of the Gila and its floodplains are Dick-Peddie (1978), Hubbard (1977), R. Johnson et al. (1974), LaBounty and Minckley (1972), USDA—Forest Serv. (1975), USDI—Bur. of Reclamation (1982), USDI—Fish Wildlife Serv. (1976), and Zimmerman (1968).

Of the many birdlists for the Lower Gila River Valley in New Mexico, none seems to apply specifically to the RNA. Seven species listed by USDI—Forest Serv. (1969) for the RNA seem to be target species, rather than species sighted: peregrine falcon, zone-tailed hawk, gray hawk, black hawk, Rivoli's hummingbird, green heron, and Montezuma quail. Zimmerman (1968) lists, in addition, the following species that would be especially affected by destruction of riparian woodland in this part of the Gila: Abert's towhee, Lucy's warbler, Wied's crested flycatcher, white-winged dove, mourning dove, yellow-billed cuckoo, and Gila woodpecker. Threats to 4 of these species are discussed by Hubbard et al. (1979). Lists and observations of birds along the lower Gila above Red Rock, but not specifically including the hard-to-reach RNA, are reported by Baltosser (in Dick-Peddie 1978), Egbert (1981), Hubbard (1971, 1977, 1978), and Zimmerman (1968, 1972).

This permanent segment of the Gila is important as habitat for at least 5 native fish species (LaBounty and Minckley 1972, Hubbard et al. 1979, Koster 1957). Surviving between Cliff and Red Rock are spikedace (*Meda fulgida*) and loach minnow (*Tiaroga cobitus*), both regarded as threatened or endangered; also longfin dace (*Agosia chrysogaster*), Gila coarse-scaled sucker (*Catostomus insignis*), and Gila mountain-sucker (*Pantosteus clarki*). Perhaps also in the RNA is the roundtailed chub (*Gila robusta grahami*), listed as threatened. Possibly the Gila chub (*Gila intermedia*) is also present, but there have been no recent collections (Hubbard et al. 1979).

Larger mammals seen in the natural area include javelina, mule deer, coyote, gray fox, black bear, mountain lion, and raccoon. Coues' whitetail deer and javelina have been reported nearby. There has been no survey for this area specifically. A 1972 tabulation by W. L. Minckley for the Hooker dam site, 19 miles upstream at the edge of a higher mountain range, is in USDI—Fish Wildlife Serv. (1976). Coatis reach their northern limit in these mountains (Kaufmann et al. 1976), and are presumably in the RNA. The last river otter reported in New Mexico was upstream of the RNA, toward Cliff (McClellan 1954). The hooded skunk is another likely species of interest.

The herpetofauna was studied by D. Johnson (1978). A tabulation by Minckley for the Hooker site is in USDI—Fish Wildlife Serv. (1976). Arizona coral snake and Gila monster are likely to be in the natural area.

Invertebrates have been surveyed for the Hooker site, 19 miles upstream (Cazier 1972) but not for the RNA.

Intrusions and Threats

Gila River RNA is out of the way and thereby well protected from casual intrusions. The area is open to cattle (USDA—Forest Serv. 1972), and browsing and trampling of cottonwood and other young trees is visible. Off-road vehicles, though forbidden south of the well-marked end of Forest Road 809, at least occasionally enter the RNA.

On the west bank at the edge of the only large alluvial fan in the RNA are the inconspicuous stone foundations of a building, apparently the 15-stamp mill built in 1885 to handle silver ore from the Telegraph Mine (west of the RNA) discussed by Gillerman (1964). Neither mine nor mill lasted long, but in 1903 "a small leaching plant with a 5-ton-a-day capacity" was erected on the same site. It too was not very successful (Gillerman 1964). The carefully built road from millsite south along the river is in good condition for 100 yards (fig. 27), but then continues as a pack trail, washed out in places, to the south edge of the RNA and beyond.

The Bureau of Reclamation, as part of the Central Arizona Project, is studying a proposal to dam the Gila 5 miles below the RNA. The Conner Dam reservoir would flood all of Gila Middle Box (USDI—Bur. of Reclamation 1982), including the RNA.

Research

Fish have been sampled in the RNA by the Bur. of Reclamation, the Fish Wildlife Serv., and by the New Mexico Department of Game and Fish. Zimmerman (1970) has studied birds and plants of the site. Others have inspected the area for raptor and other avian nest sites.

Maps

General: USDA—Forest Serv. 0.5-inch-to-1-mile series, Gila National Forest, 1974. Topographic: USDI—Geological Survey 1:62,500 series, Cliff Quadrangle, 1959. Geology: Hewitt (1959), Gillerman (1964), and Trauger (1972). Soils: Maker et al. (1971). Aerial photography: A black-and-white print, index #386 may be ordered from the Aerial Photography Field Office, ASCS-USDA, Salt Lake City.

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INKPOT RESEARCH NATURAL AREA

This 2-acre natural area has as its chief feature the Inkpot, a vertical-walled sinkhole 90 feet deep and 150 feet in diameter, currently with about 50 feet of water in it. The pond has been and may now be home to the Pecos gambusia and to *Batophora oerstedii*, a mostly-marine alga. Great horned owls and other birds nest on the cliff, and a variety of mammals and reptiles are present. The Inkpot is set in the Red Bluffs, here a 50-foot escarpment formed of the Permian Seven Rivers Formation.

Administration

Refuge Manager
Bitter Lake National Wildlife Refuge
P.O. Box 7
Roswell, NM 88201 (505) 622–6755

The Refuge is a unit of the National Wildlife Refuge System administered by the Fish and Wildlife Service, U.S. Department of the Interior. The Refuge was established in 1937; this part of it was designated a wilderness in 1970. The 2-acre (0.8-hectare) RNA was designated August 17, 1973. It was included with Lake St. Francis RNA in a Sinkhole Group as a national natural landmark in August 1980. When designated, this diminutive RNA was considered a supplement to or part of Lake St. Francis RNA; both were chosen mainly to preserve sinkhole ponds and their inhabitants.

The RNA is not marked on the ground in any way.

There has been no legal grazing by livestock in the area since 1955. Vehicles have been prohibited since wilderness designation in 1970. Deer hunting is allowed in season. The nearest non-federal minerals are 0.6 miles northwest, where rights in sec. 16 belong to New Mexico.

Location and Access

Inkpot Research Natural Area is in Chaves County at lat. 33°36′30″ N., long. 104°23′15″ W., in T. 8 S., R. 25 E., sec. 22 (E1/2 of the SE1/4 of the NW1/4) (fig. 29). There is no legal description of the 2 acres, but it is customarily mapped as a rectangle about 250 feet east-west and 350 feet north-south centered on the two Inkpots (the southern one now dry).

Inkpot RNA is in the Salt Creek Wilderness, which is between U.S. 285 and U.S. 70 in the north tract of Bitter Lake National Wildlife Refuge, 20 miles northeast of Roswell. It may be reached: (1) From U.S. 70; about 0.75 miles east of the Pecos River bridge; where Old Roswell-Clovis Highway joins U.S. 70 from the south, turn off to the north and follow the roadway 0.5 miles to its end in a small parking area (ignoring the first possible left turn onto a 2-track road). Thence walk 2.7 miles on bearing 350° True (338° Magnetic) to the Inkpot, keeping an eye out for rattlesnakes in the tall bunchgrass. (2) From U.S. 285; but this involves driving though private land on what may not be a public right-of-way: turn east on the wide, graded Red Bluff Road just south of the Salt Creek bridge, 7.5 miles north of the U.S. 285-U.S. 70 junction; follow the main road 8.0 miles east and northeast, there turn east on a bladed road; go 5.1 miles east; turn south for 2.6 miles; then short distances east and south to the Refuge boundary; thence walk the remaining 1.2 miles till the roadway ends atop the Red Bluff; the Inkpot will be visible to the right.

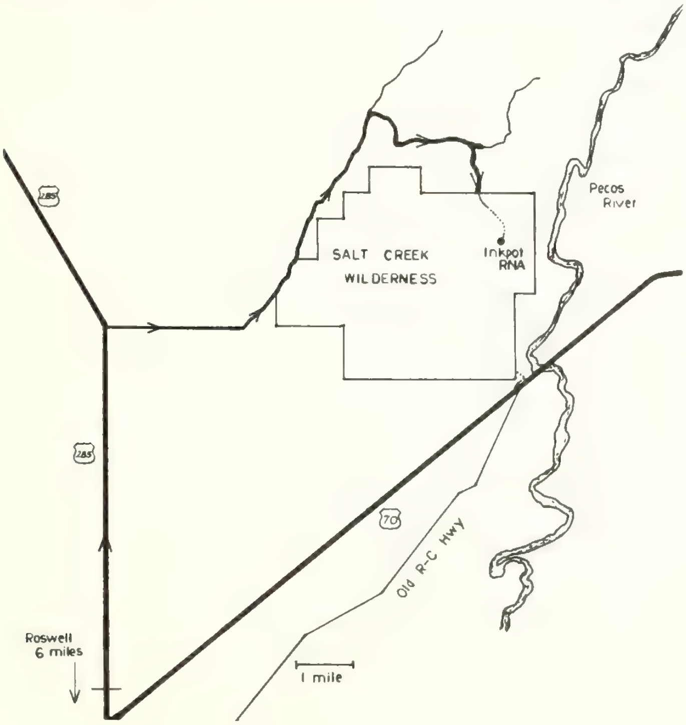

Figure 29. Inkpot RNA.

The nearest accommodations are in Roswell. Camping permits may be obtained from the Refuge Manager.

Climate

Climate of the area, warm and semi-arid, is discussed by Houghton (p. 1–2 in Lenfesty, 1983) and by Mourant (1963). Data from Refuge headquarters, 9 miles south, are the closest available, and are given in figure 11 under Bitter Lake RNA above.

Physiography, Geology, Soils

The Pecos Valley forms the westernmost section of Fenneman's (1931) Great Plains Province in New Mexico. Inkpot RNA drains to Salt Creek near its mouth in the Pecos River. The Red Bluffs mark the north side of the Salt Creek valley. Inkpot is at the foot of the Bluffs, here only about 50 feet high, 0.9 miles west of the Pecos. If the RNA boundaries are mapped as suggested above, the low elevation is 3,544 feet (1,080 m.) and the high 3,600 (1,097 m.).

Aside from the bluff, the main structural features are two sinkholes, the larger with walls vertical or partly overhung, 90 feet deep and 150 feet in diameter, currently containing about 50 feet of water. In 1937 this sink was overflowing, feeding the second, lower sink, which was also full and overflowing by a half-mile stream to a lake in the Salt Creek valley floor. In 1973 the lower sink contained several feet of water (Potter 1974). In 1982 it was dry, with sides about 15 feet high. The streambed that connected the Inkpots still drains a small area of the bluff and above, but is dry except after rains. For discussion of falling water tables in the Roswell Artesian Basin, see Lake St. Francis RNA in this report.

Walls of the upper Inkpot and most of the escarpment—that is, most of Inkpot RNA—are bare, soft, crumbly, dark red rock. This is the Seven Rivers Formation, the part of the Artesia Group directly overlying the Queen Formation (discussed under Lake St. Francis RNA), deposited mainly as evaporites at the edge of shallow Permian seas. Kelley (1971) describes this northern facies of the Seven Rivers as reddish gypsum, mudstone, and thin lithographic dolomite beds; cf. also Bachman and Stotelmeyer (1967) and Kelley (1972).

Bean (1951) describes the formation of sinkhole lakes in the Seven Rivers Formation (his Chalk Bluff Formation), and although he is writing of the Bottomless Lakes, 22 miles southward, the topographic and stratigraphic situations are like Inkpot's. According to Bean, artesian water is discharged at the hinge-line fractures at the base of the escarpment and dissolves gypsum from strata near the point of discharge, causing overlying beds nearest the river (in our case, nearest Salt Creek) to collapse. Surface runoff enlarges the sinks until they connect with channels leading from the artesian aquifer, allowing artesian water to rise in the sinks.

The early Permian Abo Formation is among the strata underlying Inkpot RNA that have potential for natural gas production (Broadhead 1982).

The Gypsumland soils, where soil is present at all, are thin and red on the severely eroded slopes. There are small pockets of other soils, probably Hollomex. The lower Inkpot contains new, deep alluvium, probably Reeves soil. See Lenfesty (1983) for soils.

Vegetation

Aquatic plants are presumably some of the same as those in Lake St. Francis RNA—*Chara*, *Potamogeton*, *Ruppia*, and the mainly-marine alga *Batophora oerstedii*—but we find no inventory for Inkpot RNA except the claim that *Batophora* is present. It is not easy to reach the water in Inkpot for sampling.

A few saltcedars (*Tamarix*) cling to the walls of Inkpot. Saltcedars have taken over the second, now-dry sink, and they line the streambed below it (figs. 30, 31).

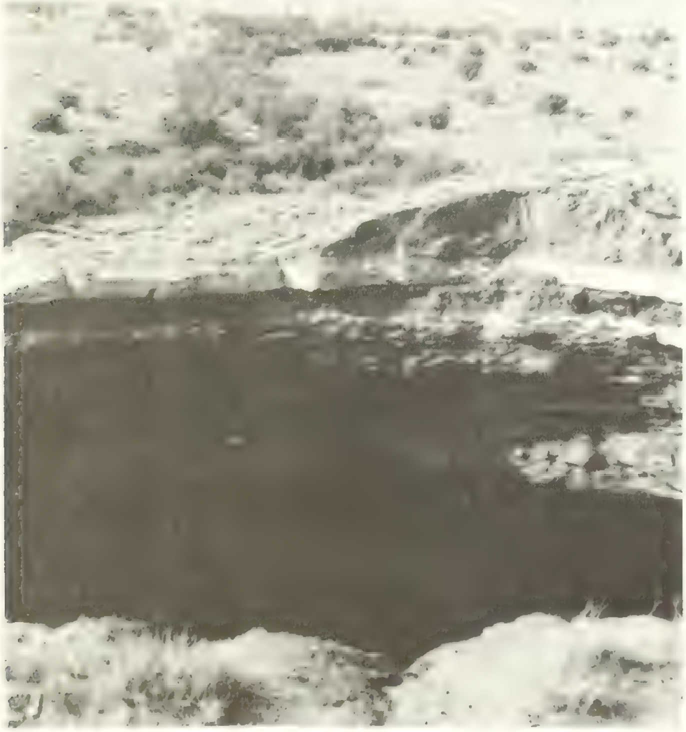

Figure 30. Looking south across the Inkpot and dry sink into Salt Creek Valley. Saltcedars.

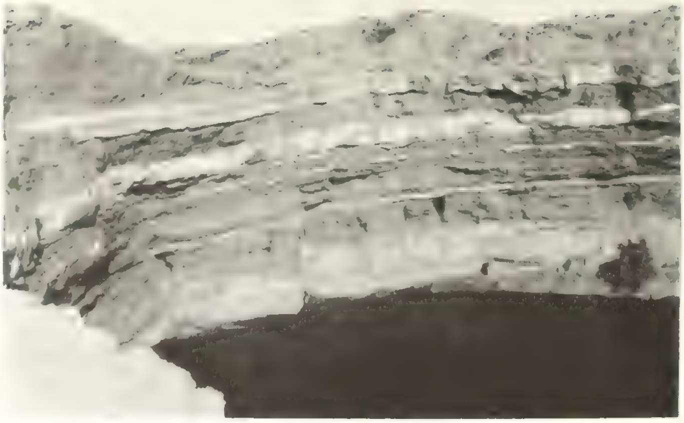

Figure 31. Forty-foot wall of the Inkpot; a saltcedar near the water.

Outside the watercourse, the small area's sparse vegetation includes many desert shrubs: snakeweed (*Gutierrezia*), creosotebush (*Larrea*), gyp bush (*Tiquilia*), mesquite (*Prosopis*), saltbush (*Atriplex canescens*), soapweed (*Yucca glauca*), prickly pear (*Opuntia engelmannii*), jointfir (*Ephedra viridis*). There is a scattering of grasses, mostly lining the small erosion channels (*Bouteloua*, *Sporobolus*, *Andropogon*, *Aristida*), and a few herbs such as gyp ringstem (*Anulocaulis gypsogenus*).

Animals

The minnow, Pecos gambusia (*Gambusia nobilis*), may already have been in Inkpot, but in any event was stocked there in 1973 by L. G. Kline (Bednarz 1975). A binocular survey by Bednarz from atop the wall in 1975 revealed no gambusia. Because it lacks shallows, Inkpot is not ideal habitat (Bednarz 1975).

Bats (unidentified) are common in the sink. Great horned owls and probably other raptors nest on the overhung walls of Inkpot. Lizards of several species scurry on the escarpment and sinkhole walls, and a roadrunner was seen pursuing them. Otherwise there seem to be no records specifically for these 2 acres. Reffalt (1968), quoted at length by Potter (1974), gives a list of mammals and herptiles for the Salt Creek Wilderness in which Inkpot RNA is located. Mule deer are the principle herbivores; coyotes are common and pronghorns rare in the vicinity of the RNA. A bird-list exists for the Refuge (USDI—Fish Wildlife Serv. 1984).

There have been suggestions over the years that a small bison herd—perhaps castrated males—should be planted in Salt Creek Wilderness. This has not happened.

Intrusions and Threats

Foundations of a cabin remain at the end of the roadway above the Inkpot, at the northeast corner of the RNA, but are scarcely visible. There is a small amount of litter, mostly decades old, around Inkpot.

State-owned mineral rights in Section 16, 0.6 miles northwest of Inkpot, could become a major problem if developed; the impact of people on wildlife here would be serious. Oil and gas development along the Refuge boundary, one to two miles north of the RNA, is proceeding rapidly in 1983 (Broadhead 1982, 1983, and observations).

Falling water tables, due in part to increased use of water in the Roswell Artesian Basin, and perhaps partly due to declining precipitation, are the greatest threat to Inkpot RNA. The recording well discussed in this report under Lake St. Francis RNA is 13 miles southwest of Inkpot RNA.

Research

No studies other than the planting of Pecos gambusia are known.

Maps

Topographic: U.S. Geological Survey 1:24,000 series, Melena Quadrangle, 1962, and 1:100,000 series, Salt Creek sheet, 1979. Vegetation: Campbell (1937). Geology: Kelley (1971, 1972). Soils: Lenfesty (1983). Aerial photography: see Lenfesty (1983).

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JORNADA DEL MUERTO RESEARCH NATURAL AREA

On the western edge of the vast Jornada del Muerto, these 11,000 acres of sands are covered by sand sagebrush, broom pea, and dropseeds, with smaller areas of mesquite hummock, creosotebush, black grama, and free dunes. Pronghorn, mule deer, coyote, and a variety of smaller wildlife such as burrowing owls are common in the shrubland.

Administration

Refuge Manager
Bosque del Apache National Wildlife Refuge
P.O. Box 1246
Socorro, NM 87801 (505) 835–1828

Jornada del Muerto is one of 5 natural areas in Bosque del Apache Refuge, a 57,191-acre unit of the National Wildlife Refuge System administered by the Fish and Wildlife Service, U.S. Department of the Interior. The Refuge was established in 1939 on land purchased by the federal government in 1936 after many decades of grazing and overgrazing. The approximately 11,000-acre (4,450-hectare) RNA was designated August 17, 1973. In 1975 the RNA was included by the Congress in a new 19,859-acre Little San Pascual Wilderness.

Our estimate of 11,000 acres for the RNA differs from two official estimates, 10,000 and more recently 9,133 acres. The Refuge Manager has written (in 1979 and 1982) that the south boundary is the actual road, used for patrol purposes, that heads east from just south of the Little Black Mesas. However, maps that the Fish and Wildlife Service has used for computation and for administration have shown another road (the one appearing on the 1948 Val Verde and San Antonio 15-minute topographic quadrangles), which no longer exists. It lay wholly north of the existing road, and the difference in position would account for much of the difference in acreage.

The Research Natural Area is closed to vehicles and to all mineral entry. It is open in season for deer, quail, and rabbit hunting. It has not been grazed legally for several years, but appreciable trespass grazing occurs. Even when the area was legally open there were rancher-Refuge battles over cattle numbers and times for grazing. The east (Refuge) boundary is well fenced and marked "unauthorized entry prohibited," but otherwise the RNA is not posted.

Location and Access

Jornada del Muerto Research Natural Area is in Socorro County, centered at lat. 33°47′15″ N., long. 106°49′45″ W. (fig. 32). Had the area been surveyed it would be in T. 6 S., R. 1 E., and the south edge of T. 5 S., R. 1 E. The north boundary lies along lat. 33°50′ N.; the west boundary goes south from 33°50′ N. along an old fence-line for 1.1 miles, then about southwest for 2.5 miles, then along a (mostly) buried pipeline south-southwest to an arroyo and road just south of conspicuous sandstone buttes; the south boundary follows that road easterly to the east boundary of the Refuge near its intersection with T. 6 S.-T. 7 S. line; and the east boundary runs north-northeast along the Refuge fence to point of beginning. The sandstone buttes—Little Black Mesas—are just outside the RNA. San Pascual RNA is adjacent to the south, and the roadway between them is the one labeled "Pack Trail" on the 1982 topographic map.

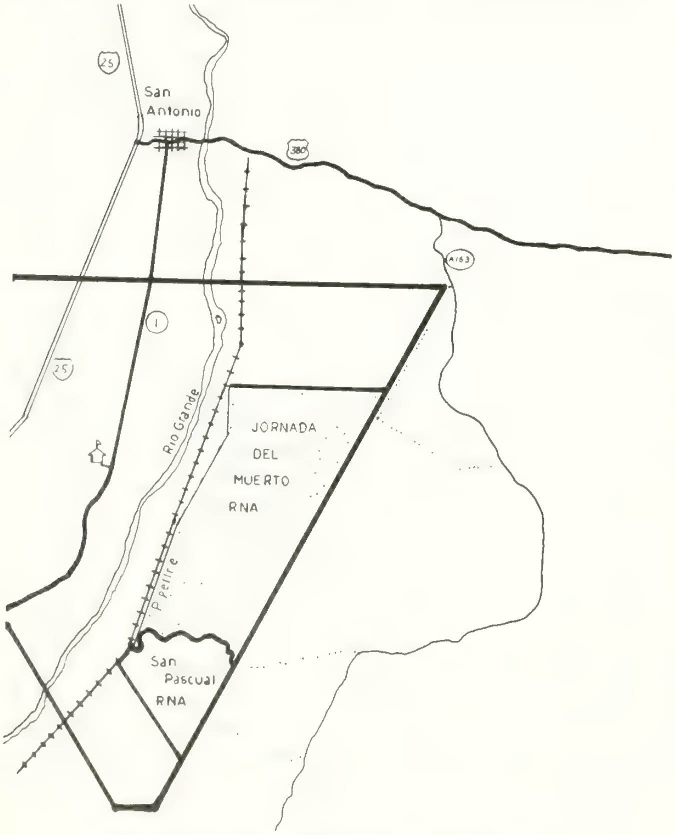

Figure 32. Jornada del Muerto RNA.

The east side of Jornada del Muerto RNA is reached by turning south from U.S. 380 on Socorro County A153: that junction is 7.4 miles east of the San Antonio exit from Interstate 25, or 5.7 miles east of the Rio Grande. From U.S. 380 drive south 5.8 miles, where turn west on a poorly bladed road. Pass a large metal stock tank at 6.9 miles from U.S. 380 and bear right (northwest) along the fence to the remains of a tank and windmill at the RNA and Refuge boundary, 9.3 miles from U.S. 380. This is the southeast corner of T. 5 S., R. 1 E., near the northeast corner of the natural area.

The southeast corner of Jornada del Muerto RNA is the northeast corner of San Pascual RNA, and may be reached by directions given under the latter.

Another approach, open only during daylight, is from Bosque del Apache Refuge headquarters. Follow directions to Apache Camp RNA given above under that heading; leave it on the left and cross the Main Conveyance Channel; jog north a few yards till a road goes east over the high dike; follow that road to the natural channel of the Rio Grande. In season—often September to February—the channel may be drivable; if not, it can usually be waded. The RNA is about 1.1 miles east of the river at this point. Do not drive into the wilderness area.

Accommodations are in Socorro.

Climate

The climate of Socorro County is discussed by Houghton (p. 7–9 in Maker et al. 1972): the area is warm and arid, with most of the 8 inches (200 mm.) of precipitation coming in late-summer thunderstorms. Data from Refuge headquarters, about 2.5 miles west of Jornada del Muerto RNA, are given in figure 7 above under Apache Camp RNA.

Physiography, Geology, Soils

This is the Mexican Highlands section of the Basin and Range Province. The west-sloping terraces that underlie the RNA, now 1 to 3 miles from the Rio Grande, were deposited in late Tertiary or Quaternary time. Elevation in the natural area varies from 4,525 feet (1,379 m.) along the western border to 4,830 feet in the northeast and 4,855 feet (1,480 m.) in the southeast corner.

The Jornada del Muerto—the great trough and plain in which the RNA is located—extends at least 150 miles from Socorro south through Sierra to Doña Ana counties; or in Fenneman's (1931) interpretation, the whole 260 miles from Albuquerque to El Paso. The Spanish Trail to Santa Fe followed much of the Jornada, and death by thirst and by the hands of robbers is said to have marked the route with bones (Keyes 1905), hence the name, "journey of the dead man." Surface drainage in most of the RNA is to the Rio Grande, but several parts drain east to the Jornada, which here has no outlet, and the northeastern 1,000 acres drain to a slight depression within the RNA.

Sand dunes cover 40 acres or so in the south; there is poorly anchored sand in most parts of the RNA, and blowouts to 60 feet in diameter are scattered in the sandy areas. In the southwestern section there are gravelly ridges with no sand.

There is no permanent water in the natural area except at Antelope Well, a windmill, drinking trough, and small overflow pond in the east-center of the area, maintained by Refuge personnel.

There are a few rock outcrops along west-facing slopes through the north-south center of the RNA. These are apparently Tertiary or Pleistocene rhyolites that have been assigned to the Santa Fe Group (Dane and Bachman 1965). In the southwestern corner of the natural area, and more prominently just outside it, are outcrops of red Baca Formation sandstone, of early Tertiary age. Outside the RNA the sandstone rises in 150-foot buttes, the Little Black Mesas.

Soils are of the Berino-Bluepoint-Onite Association (Maker et al. 1972), classified as an Aridsol of Haplargids-Torripsamments construction. These are deep soils in which thin, sandy loams cover several feet of subsoil that varies from clay loam to sand. Minor, even sandier members of the association, such as Pintura soils, may be prominent in the RNA.

Vegetation

Sand sagebrush (*Artemisia filifolia*) and broom pea (*Psorothamnus* or *Dalea scoparia*) dominate the sandy sites—80 to 90% of the Research Natural Area (fig. 33). They occur either together or with one or the other the single dominant in patches of one to several acres. Between shrubs, dropseeds are common: *Sporobolus cryptandrus, S. contractus*, and, on the deepest sands, *S. giganteus* to 6 feet tall. Indian ricegrass (*Oryzopsis hymenoides*) occurs with the dropseeds. Isolated or in small patches over most of the RNA are junipers (*Juniperus monosperma*), soapweeds (*Yucca glauca*), fourwing saltbush (*Atriplex canescens*), mesquite (*Prosopis glandulosa*), snakeweed (*Gutierrezia sarothrae*), and other subshrubs of the composite family. In the north mesquite is common, holding sand in hummocks, with broom pea and sand sagebrush between hummocks (fig. 34). When moisture permits, many annuals cover the sand, such as devil's-claw (*Proboscidea*) and heliotrope (*Heliotropium*).

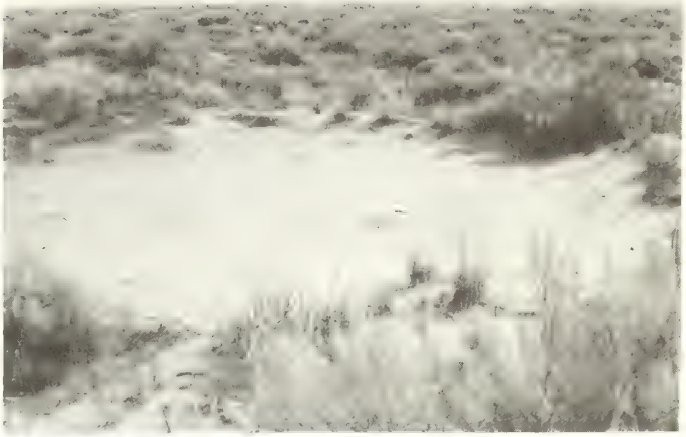

Figure 33. Sand blowout with broom pea, sand sagebrush, and dropseed. Jornada del Muerto RNA.

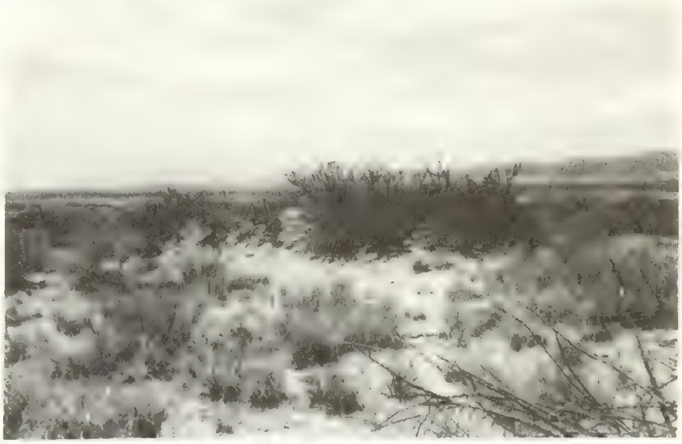

Figure 34. Mesquite hummock with dropseeds and broom pea. Jornada del Muerto RNA.

Small areas around Antelope Well are dominated by creosotebush (*Larrea tridentata*) and, on ridges, by jointfir (*Ephedra*). There is some black grama (*Bouteloua eriopoda*) near the southeast corner of the RNA.

A small, artificial pond by Antelope Well has cattails (*Typha*) and saltcedar (*Tamarix*). Saltcedars have been cut around a small playa there. They also grow near a dam in the southwest corner of the RNA.

Probably all the area suffers from past overgrazing, but there is no control area for comparison. Many acres of the RNA near the now-abandoned Fite Well near the northeast corner still have annual weeds as their main cover.

Donart et al. (1978) map this as Chihuahuan Desert Grassland: Mixed Dropseeds-Black Grama Association (Type CG4a), which includes sand sagebrush locally. Their Type CG4c, Mixed Dropseeds-Indian Ricegrass, is perhaps more appropriate for these sandy slopes.

Animals

Pronghorns and black-tailed jackrabbits are the conspicuous herbivores; mule deer are also here. Scaled quail are common, and there are burrowing owl nests. Golden eagles are not uncommon, though red-tailed hawks are more regularly present. Blowouts and dunes are criss-crossed with tracks of insects, lizards, snakes, quail and other birds, pronghorns, and coyotes.

Studies from farther south on the Jornada plain are helpful for animal ecology (e.g. Howard et al. 1973, Whitford 1976), but do not deal with the broom pea-sand sagebrush community, on which nothing has been published.

Archaeology

The San Pascualito Pueblo ruins on Little Black Mesa are about 1,300 feet outside the RNA. Surveys in 1932, 1940, and 1978 lead to belief that the pueblo was abandoned by 1359 A.D., with possible brief re-occupation in the fifteenth century. Unpublished data are available at the Museum of New Mexico Laboratory of Anthropology in Santa Fe under Site No. 756.

Intrusions and Threats

A 600-yard-long road leads from the west to Antelope Well, a conspicuous windmill, tank, and pond in the east center of the RNA. The pipeline buried in 1954 along part of the west boundary is above ground from place to place, but neither it nor the seldom-traveled two-track road that accompanies it is conspicuous. Occasional small signs mark the pipeline route. Although 1948 topographic maps show two roads across the RNA, they are now difficult or impossible to find.

In the extreme southwest of the area on San Pascualito Arroyo is a 20-foot-high stone dam and pond area dating from the 1930's. It is filled in and covered by half an acre of saltcedar. The pond holds surface water for only a short time after rains.

Signs of trespass cattle are common.

Research

None is known.

Maps

Topographic: USDI—Geological Survey 1:24,000 series, San Antonio Quadrangle, 1982; and for the southernmost half-mile also the Little San Pascual Quadrangle, 1982. Previous topographic maps and the 1979 Bureau of Land Management quadrangle are excessively misleading as to roads. Eastern approaches to the Refuge are covered on the Cerro de las Campana 1:24,000 Quadrangle. Soils: Maker et al. (1972). Geology: Bachman and Stotelmeyer (1967), Weir 1965.

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LAKE LUCERO RESEARCH NATURAL AREA

Lake Lucero, the usually dry remnant of Pleistocene Lake Otero, occupies the hot, dry bottom (3,900 feet elevation) of the Tularosa Basin. This salt-encrusted plain "grows" selenite crystals, rather than vegetation, from groundwater. Alkali sacaton and Chihuahuan Desert shrub steppe grow west of the Lake.

Administration

Superintendent
White Sands National Monument
P.O. Box 458
Alamogordo, NM 88310 (505) 437–1058

White Sands National Monument, established in 1933, is a 230-square-mile unit of the National Park System administered by the National Park Service, U.S. Department of the Interior. Lake Lucero RNA was established September 26, 1969, with an area of 5,760 acres. It is in the western part of the Monument that is governed by a co-use agreement with the U.S. Army, 35% of whose missile flights at White Sands Missile Range overfly the co-use area.

Hunting, livestock grazing, vehicles, and collecting are prohibited in the RNA. The land is withdrawn from all mineral entry. Missiles and visitors are permitted under strict controls aimed at keeping them apart. A clause in the co-use agreement states that missile impacts in the Lake Lucero crystal beds are to be avoided.

Location and Access

Lake Lucero Research Natural Area is in eastern Doña Ana County within White Sands National Monument and White Sands Missile Range. It is centered at lat. 32°42′30″ N., long. 106°27′00″ W., (fig. 35), and comprises secs. 16, 20, 21, 29, and 32 of T. 18 S., R. 5 E., and secs. 3, 4, 5, and 10 of T. 19 S., R. 5 E.—9 square miles (5,760 acres or 2,331 hectares).

Monument headquarters are on U.S. 70 and 82, 15 miles southwest of Alamogordo or 63 miles northeast of Las Cruces.

The RNA may be visited only with permission of White Sands National Monument personnel. Vehicular access requires permission and escort also from White Sands Missile Range, U.S. Army. Public tours from Monument headquarters to Lake Lucero are arranged on a bimonthly basis. Their route is Missile Range Road 7 from its intersection with U.S. 70–82 15 miles north to the west side of Lake Lucero.

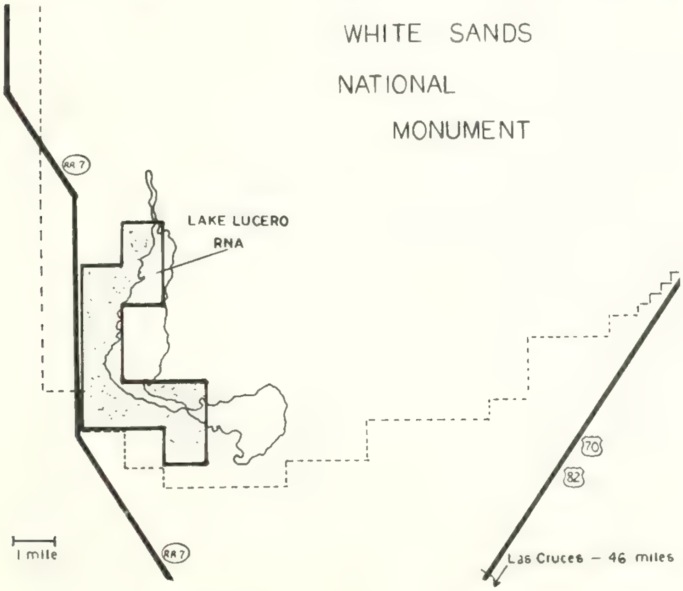

Figure 35. Lake Lucero RNA.

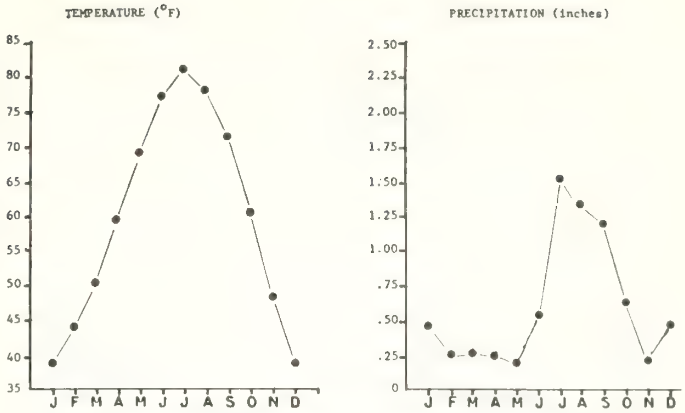

Figure 36. Climate of Lake Lucero RNA.

Accommodations are in Alamogordo or Las Cruces. The nearest campgrounds are 35 miles northeast in Lincoln National Forest and 30 miles southwest at Aguirre Springs. Overnight hiking in the Monument requires clearance and registration at Monument headquarters.

Climate

Lake Lucero is in a hot, arid valley with a daily temperature range that often exceeds 60° F. Arctic cold and Gulf of Mexico rains tend not to penetrate the Tularosa Basin: summer air from the Gulf drops 50% more precipitation on the far, eastern side of the Sacramento Mountains than on the western. Regional warmth and aridity are compounded by the reflective properties of gypsum, which cause warmer days and cooler nights here. In the 1970's precipitation averaged 7.8 inches (200 mm.) with a 33% standard deviation. Mean annual temperature was 60°F (15.5°C), with a high of 110°F (43.3°C) and low of −14°F (−25.5°C) at Monument headquarters. Annual potential evapotranspiration is about 30 inches (762 mm.). Climate is discussed by Neher and Bailey (1976), Reid (1980), and other sources listed below. Monthly averages from the Monument weather station (Index No. 9686) are shown on figure 36.

Physiography, Geology, Soils

The Tularosa Basin, in which the White Sands are located, occupies a much-faulted graben between the San Andres Mountains on the west and the Sacramento Mountains on the east. The basin, fully described by Meinzer and Hare (1915), is a flat-floored bolson extending 125 miles north-south in New Mexico. It is classified by Fennemen (1931) in the Sacramento Section of the Basin and Range Province.

The alkali flat in whose southern end Lake Lucero is situated covers about 165 square miles, with gypsum dunes to 100 feet high to the east and alluvial slopes derived from the San Andres Mountains to the west. Elevation of the playa is about 3,900 feet (1,189 m.) throughout. West of the lake the RNA rises to 4,025 feet (1,227 m.).

Pleistocene Lake Otero occupied the Tularosa Basin during the period 24,000–4,000 years before present (Herrick 1904, Hendrickson 1983). Lake Lucero, usually surface-dry but with the soil wet, is its depauperate descendant. "The alkali flats practically represent the water table laid bare by wind erosion" (Fenneman 1931). This groundwater is too alkaline for drinking, with pH about 8, and about 35,000 mg. per liter of dissolved solids including sulfate 1.85%, sodium 1.4%, chloride 1.8%, and magnesium 0.3% of total weight. Hydrology here has been well studied, notably by Meinzer and Hare (1915), Kottlowski (1958), and Allmendinger and Titus (1973). The majority of the gypsum in the White Sands was undoubtedly derived from the primary evaporites of Lake Otero. Groundwater discharging at Lake Lucero may have produced enough crystalline gypsum to make up as much as 33% of the White Sands (Allmendinger and Titus 1973).

Shores of the lake within the RNA are covered with brownish-golden selenite crystals, colored by silt, which flake in rhombic crystals similar to mica (fig. 37). Some crystals are several feet long, and were used in early days for windows. Crystals continue to form from calcium sulfate brought by groundwater.

Geology of the Tularosa Basin is well known (Herrick 1904, Meinzer and Hare 1915, Sandeen 1954, summarized by Dodge 1971). The Permian Yeso and San Andres Formations underlie this part of the Basin and are the source of most of the gypsum there. In the San Andres Mountains just west of the RNA, 40% of the 1,580-foot-thick section of the Yeso (= "gypsum") Formation is gypsum. These are Permian strata deposited in the Delaware Basin during that period.

No bedrock is exposed in the RNA. Overlying bolson deposits may be 6,000 or more feet thick, comprising red clay and silt intercollated with sands, conglomerates, and gypsum and salt beds.

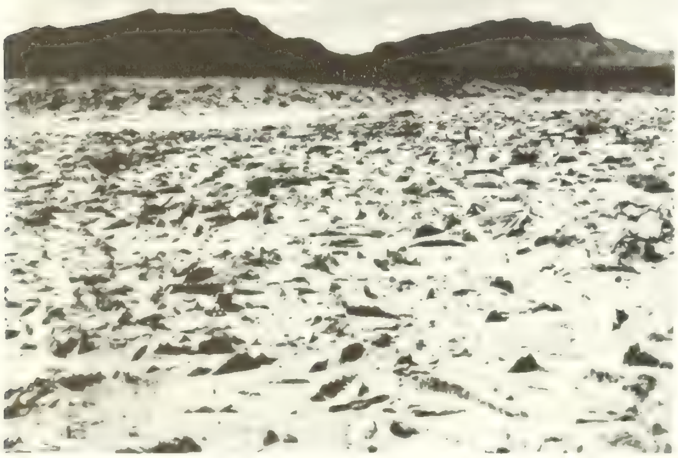

Figure 37. Selenite crystal bed, Lake Lucero. (Courtesy of White Sands National Monument.)

Three soil types are mapped for the RNA, all classified in the Gypsum Land great group (Neher and Bailey 1976). Predominant along the lakeshore is the Marcial-Uber Association, including 55% Marcial silty clay loam and 35% Uber silt loam. On alluvial slopes to the west and south is the Mimbres-Glendale Association with 55% Mimbres silt loam and 25% Glendale silt loam. At the northern tip of the RNA an area is mapped as Doña Ana Complex Dune Land; but recognizable dunes begin about 1,800 feet east of the RNA.

Vegetation

Although plants of the Tularosa Basin and of the Monument as a whole are well documented (Shields 1956, USDI—Nat. Park Serv. 1973, U.S. Army 1975, Reid 1979–80), available data relating plants specifically to the alkali flat at Lake Lucero are few. Emerson (1935) states that only scattered individuals of sand verbena (*Abronia angustifolia*) and iodine bush or burroweed (*Allenrolfea occidentalis*) grow on the alkali flat; only the latter was common in 1984. Reid (1980b) lists an association including mainly iodine bush and also four-wing saltbush or chamiza (*Atriplex canescens*), seepweed (*Suaeda torreyana*), saltcedar (*Tamarix gallica*), and alkali sacaton (*Sporobolus airoides*) for Lake Lucero (fig. 38).

The RNA extends up to a mile south and west of the lake flat onto the 1–5% east- and north-facing slopes of alluvial deposits. There, in what Neher and Bailey (1976) call clay grasslands, are alkali sacaton, tobosa (*Hilaria mutica*), four-wing saltbush, creosotebush (*Larrea divaricata*), and burrograss (*Scleropogon brevifolius*). Thus the predominant vegetation type of the RNA is Küchler's Type 58, grama-tobosa shrub steppe.

Other plants that are near and probably are within the RNA (Neher and Bailey 1976) include coldenia (*Tiquilia hispidissima*), knifeleafcondalia (*Condalia spathulata*), mesquite (*Prosopis glandulosa*), jointfir (*Ephedra torreyana*), gyp grama (*Bouteloua breviseta*), rosemarymint (*Poliomintha incana*), saltgrass (*Distichlis spicata*), and vine mesquite (*Panicum obtusum*).

The rosy hue that Lake Lucero sometimes takes on when wet is due to growth of purple sulfur bacteria (Dodge 1971 and Hendrickson 1983).

Animals

Twelve snake, 11 lizard, and 1 turtle species are known for the vicinity (Bugbee 1942, Dixon and Medica 1967, USDI—National Park Service 1973). On the white dunes of the Monument some species are much whiter than elsewhere, and subspecies have been described; but this may not be relevant to the RNA itself. Noteworthy are Cowles prairie lizard (*Sceloporus undulatus cowlesii*) and the bleached earless lizard (*Holbrookia maculata ruthveni*).

Mammals are well studied in the Monument but not in the RNA (Dice 1930, Benson 1933, USDI—National Park Service 1973). Of rodents, at least *Perognathus* *penicillatus*, *Dipodomys merriami*, *Onychomys torridus*, *Neotoma micropus*, and *Thomomys bottae* (*T. baileyi*) would be expected west of Lake Lucero (Blair 1943). Coyote, kit fox, desert cottontail, and black-tailed jackrabbit are present, as is the introduced gemsbok (Reid and Patrick 1983).

Stroud (1950) lists 8 insect species from the RNA.

Archaeology

A large unit house of the El Paso phase of Mogollon culture, dating from about 1250 A.D., is in Section 5 of the RNA. Dwellings and accompanying facilities may have occupied 100 acres. The pueblo has been exposed by erosion and material including Brown Ware pottery is scattered over half the section. Two human burial sites have been excavated (Eidenbach and Wimberly 1980).

This is Human Systems Research (Tularosa) site 702–1 and Museum of New Mexico (Santa Fe) site 21162.

Intrusions and Threats

Old roads in south and west parts of Lake Lucero RNA are said to have disappeared, or nearly so. However, the wilderness study (USDI—Nat. Park Serv. 1969) mapped 1.3 miles of road in Section 32 that had not appeared in older maps. Missile Range Road 7 runs along 4 miles of the RNA's western border. The natural area is not fenced. There are single traverse stations (concrete posts?) in Sections 5 and 10. Missile Range structures in the co-use area may also be in the RNA (U.S. Army 1975, USDI—Nat. Park Serv. 1971). Remains of corrals and buildings are west of the lake (Hendrickson 1983), and the area was seriously overgrazed.

Location within White Sands Missile Range as well as within White Sands National Monument in some ways gives extraordinary protection to the RNA. Nearly all visitors are in bi-monthly tour groups accompanied by military police and Monument rangers. Crystal collecting by military personnel is known but thought not to be common.

Figure 38. Selenite and dropseeds. Lake Lucero RNA. (Courtesy of White Sands National Monument.)

The number of planned missile impacts in the co-use area as a whole—74,849 acres—was reduced from an average of 25 to 30 per year to 10 in 1972, 9 in 1973, and 4 in 1974 (U.S. Army 1975). None are planned for the Lake Lucero area itself, but they occur; impacts during 1963–1971 are mapped by USDI—Nat. Park Serv. (1971). Impacts include space vehicles and parts of towed targets. Debris is cleared by helicopter under supervision of National Park Service personnel. Missile impacts have been studied by Moore (1976) and the degree of intrusion on the Monument is discussed by Niklaus (1977). Missile activity was given as the reason for a recommendation that none of the Monument be designated wilderness (USDI—Nat. Park Serv. 1971).

Flights in addition to missiles include Missile Range planes and 4 to 10 helicopter flights over Monument land daily, and Holloman Air Force Base aircraft based 19 miles northeast of the RNA.

Industrial development—a multi-billion-dollar "energy park"—is contemplated near Alamogordo, some 25 miles northeast. Possible heavy use of Tularosa Basin groundwater would have serious impact on Lake Lucero (cf. Allmendinger and Titus 1973, and literature cited by Garza and McLean 1977 and in current Basic Data Reports of the New Mexico State Engineer).

Introduced organisms that alter ecological balance of the RNA are saltcedar (Reid 1980) and gemsbok (Reid and Patrick 1983, Saiz and Decker 1975).

Research

Allmendinger studied the source of sulfate for selenite crystals formed at Lake Lucero (Allmendinger and Titus 1973). R. Anderson studied mineral content of water at Lake Lucero in 1965 (Monument file N22 WHSA). The Army contracted core samples at the Lake in 1966 (see the same file). W. H. Reid and his students of University of Texas—El Paso continue to produce reports on vegetation and other aspects of ecology of the Monument, including Lake Lucero; see "References" below. Stroud (1950) looked at insects of the RNA. For archaeological research see Eidenbach and Wimberly (1980). Other research in the Monument has concerned the RNA at least incidentally.

Maps

Administrative: see U.S. Army and USDI sources cited below. Topographic: USDI—Geological Survey 1:24,000 series Lake Lucero Quadrangle, 1948; 1:100,000 series White Sands sheet, 1982. Geology: USDI—Geological Survey 1:500,000 Geologic Map of New Mexico, 2 sheets, 1965, by Bachman and Dane, and N.M. Bur. Mines & Min. Resources Geol. Map 14, 1960, by Kottlowski. Soils: Neher and Bailey (1976). Vegetation: Reid (1980). Aerial photography: Neher and Bailey (1976), Hendrickson (1983) and U.S. Army (1975).

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LAKE ST. FRANCIS RESEARCH NATURAL AREA

More that 30 sinkholes puncture the gypsum-rich bedrock of these otherwise level 700 acres. Several holes contain salt-tolerant fish: the endangered Pecos gambusia, the Pecos pupfish, green sunfish, and others. The green filamentous alga *Batophora oerstedii*, otherwise known from the Gulf of Mexico, is common here. Terrestrial vegetation is desert shrub steppe dominated by alkali sacaton and saltgrass on flats and grama and other grasses on uplands, with several obligate gypsophiles.

Administration

Refuge Manager
Bitter Lake National Wildlife Refuge
P.O. Box 7
Roswell, NM 88201 (505) 622–6755

The Refuge is a unit of the National Wildlife Refuge System administered by the Fish and Wildlife Service, U.S. Department of the Interior. Bitter Lake Refuge was established in 1937. The 700-acre (283-hectare) research natural area was designated August 17, 1973. It was made a National Natural Landmark in August 1980.

Entry requires a permit from the Refuge Manager. Hunting, fishing, swimming, and livestock grazing are prohibited. Mineral rights in Section 32, which contains 360 acres of the RNA, belong to New Mexico, only the surface rights having been purchased by the federal government in 1937.

North and west borders of the RNA coincide with the Refuge boundary, which is fenced and posted. The research natural area is not marked as such, but there are "no unauthorized entry" signs at likely routes into the area.

Location and Access

Lake St. Francis Research Natural Area is in Chaves County, centered at lat. 33°29′15″ N., long. 104°25′10″ W., (fig. 39) in T10S R. 25 E., secs. 4 and 5 and T. 9 S., R. 25 E., sec. 33 and, mainly, sec. 32. The boundary is described from the northeast corner of T. 9 S., R. 25 E., sec. 32: E. 1,320 feet thence S.7,260 feet thence W. 2,640 feet thence N. 660 feet thence W. 2,640 feet thence N. 3,960 feet thence E. 1320 feet thence N. 1,320 feet thence E. 1,320 feet thence N. 1,320 feet thence E. 1,320 feet to point of beginning.

The RNA is 2 miles north-northwest of headquarters in the south tract of Bitter Lake National Wildlife Refuge, 14 miles northeast of Roswell. Access to the Refuge is either from U.S. 380, 3.7 miles east of the center of Roswell, or from U.S. 70–285 4 miles north of the center.

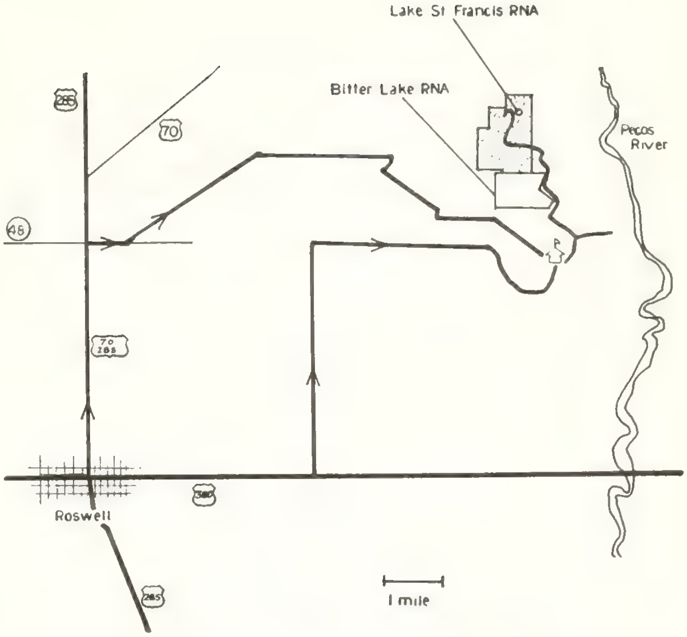

Figure 39. Lake St. Francis RNA.

Given an entrance permit, the RNA is reached on graded roads that lead north through the Refuge headquarters area.

The nearest accommodations are in Roswell.

Climate

The region is warm and semi-arid, with precipitation about 10 inches (250 mm.) in the Refuge or 13 inches (330 mm.) from Roswell data over a longer period. More than half the precipitation comes during the summer, mostly in thundershowers. Climate is discussed by F. E. Houghton (in Hodson et al. 1980) and by Mourant (1963). Monthly data from Refuge headquarters are given in figure 11 above under Bitter Lake RNA.

Physiography, Geology, Soils

The Pecos Valley is at the western border of the Great Plains Province. These valley plains presumably resulted from erosion by the Pecos River of a formerly broader Llano Estacado, now 45 miles to the east. Bitter Lake Refuge is within the Roswell Artesian Basin, which receives water from highlands to the west. The RNA is just west of the current floodplain of the Pecos River and is 1.25 miles west of the river.

Within the RNA elevation rises gradually from 3,495 feet (1,065 m.) in the southeast corner to 3,543 feet (1,080 m.) in the northwest, an average slope of less than 1%. Several areas appear flat, and about 40 acres in the northeast of the RNA form a shallow depression with no external drainage. Twenty-nine small, round, steep-sided sinkholes in the RNA have been assigned numbers (Bednarz 1975) and there are several others. All once held water, and several still do (fig. 40). The largest is Lake St. Francis, 200 feet across with sides (in late 1982) 15 feet high above the 44-foot-deep water. Sinks form by collapse of overlying strata into hollows formed by solution of pockets of gypsum, and may exceed 100 feet in depth (Bean 1951). One pothole appeared during the 1930's, and two not-yet-collapsed domes are known in the RNA.

Water level varies from one sink to another, but all are alike in that levels have, on average, been going down for many years. Variations in water level depend on the artesian head, which in turn depends on recharge in the Hondo and adjacent basins to the west, mostly in Lincoln County (Bean 1951, Fiedler and Nye 1933, Mourant 1963). Quality of the brackish water varies. Dissolved solid concentrations as high as 22,550 mg./liter have been measured, but at least 5 sinks and Dragonfly Spring—the waters supporting Pecos gambusia in the RNA in 1975—had solids at 5,050 mg./liter or less (Bednarz 1975).

Bitter Creek (or North Fork of Lost River), a small, intermittent stream, flows southward through the west side of the natural area into Bitter Lake, which lies just to the south (see Bitter Lake RNA in this report). Streamflow is augmented in the southeast part of Lake St. Francis RNA by Dragonfly Spring.

Surface strata are Pleistocene and Recent gypsiferous alluvium, including terrace gravels in the southern part of the RNA. Gypsiferous bedrock is closely underlying in most parts of the area, and is exposed in the sinks. These strata are siltstones and gypsum of the Queen Formation, deposited along with other members of the Artesia Group during Permian times in a shelf sea extending north from the deeper Delaware Basin (Kelley 1971). In sinks the rock layers are usually coated with recent gypsum deposits from the water.

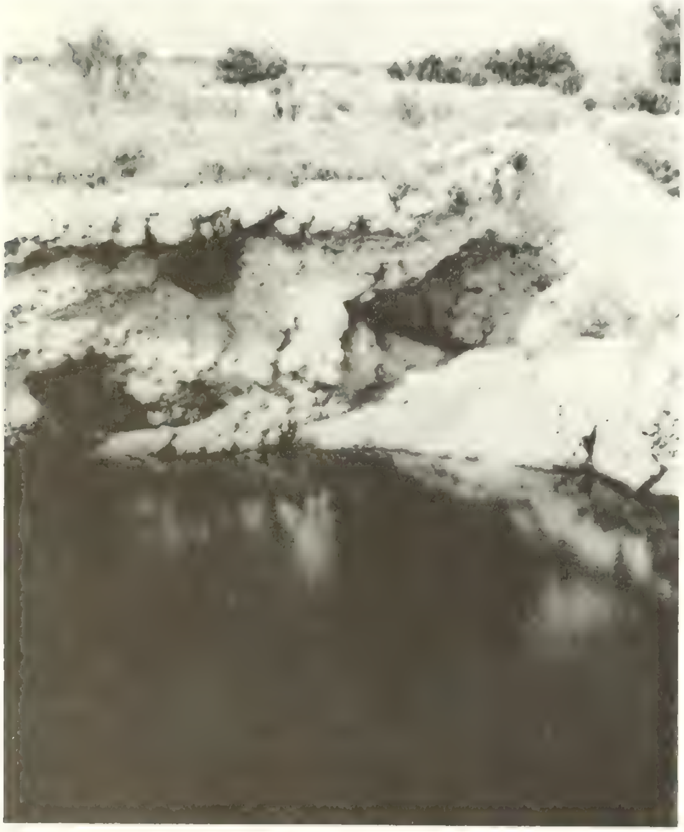

Figure 40. A sinkhole, with old channels exposed by falling water levels. The larger shrubs are saltcedars. Lake St. Francis RNA.

Of deeper underlying strata the early Permian Abo Formation, some 4,400–5,100 feet below the surface, is of particular interest: 3 wells in the township (T. 9 S., R. 25 E.) are yielding natural gas, and exploration continues apace (Broadhead 1982). A small oil-producing field exists 2.5 miles south of the RNA.

Sand, clay, stone, and gypsum are quarried in the vicinity.

Soils are mapped as Holloman and Gypsumland of the Gypsiorthids, Torriorthents, and Gypsumland great groups. In general this map unit contains 60% Holloman loam (some with a thick A–2 solum), 30% Gypsumland, and 10% other soils (Hodson et al. 1980). The moisture regime is borderline between aridic and ustic-aridic. Abundant gypsum in all these soils is highly susceptible to solution. White gypsum crusts form from evaporation in flat areas.

Vegetation

Aquatic plants are mainly the structurally complex alga, musk grass or stonewort (*Chara*); pondweed (*Potamogeton pectinatus*); ditch grass or wigeon grass (*Ruppia maritima*); and, of special interest, the green alga *Batophora oerstedii* (order Siphonocladales), of which the known distribution includes only coastal waters and lagoons from Bermuda to the Gulf of Mexico plus these sinkholes.

At the edges of ponds and along Lost River are often a few rushes (*Scirpus*), cattails (*Typha*), reeds (*Phragmites*), and the invasive, Old World saltcedar (*Tamarix*) (fig. 40). Some of the newly dry sinks also have these 4-to-10-foot-high plants.

Salt flats and depressions are dominated by alkali sacaton (*Sporobolus airoides*) and saltgrass (*Distlichis spicata*), with scattered shrubs including saltcedar, baccharis (*Baccharis emoryi and B. glutinosa*), and *Clappia suaedifolia* (*Pseudoclappia arenaria*) (fig. 41). An unusual assemblage of herbs includes sea lavender (*Limonium limbatum*), sea purslane (*Sesuvium verrucosum*), iodinebush (*Allenrolfea occidentalis*), threadleaf (*Sartwellia flaveriae*), and a beautiful, occasionally bush-like centaury (*Centaurium texense*).

Uplands are covered with grasses and shrubs, the former commonly gramas (mainly *Bouteloua breviseta*; also *B. gracilis, B. eriopoda, B. hirsuta, B. barbata*), tobosa (*Hilaria mutica*), sacatons (*Sporobolus airoides* and *S. wrightii*) and dropseed (*S. cryptandrus*), sprangletop (*Leptochloa dubia*), fluffgrass (*Erioneuron pulchellum*), ring muhly (*Muhlenbergia torreyi*), and three-awns (*Aristida* spp.). Shrubs and subshrubs include snakeweed (*Gutierrezia*), soapweed (*Yucca*), gyp bush (*Tiquilia*), saltbush (*Atriplex canescens*), jointfir (*Ephedra*), rayless goldenrod (*Isocoma wrightii*), mesquite (*Prosopis*), and saltcedar. Gyp ringstem (*Anulocaulis gypsogenus*) is among several interesting herbs.

Küchler (1975) and Donart et al. (1978) map potential natural vegetation for Bitter Lake Refuge as Chihuahuan

Desert Shrub (Küchler's Type 44, Creosotebush-Tarbush), but the characteristic species are scarcely represented now. More appropriate, perhaps, is the gypsum facies of Donart's Sacaton-Tobosa Association (Type CG4d), with alkali sacaton dominant in depressions and gramas and tobosa on uplands.

Animals

Of prime interest is a minnow, the Pecos gambusia (*Gambusia nobilis*), listed as endangered by federal and state authorities and surviving only on the Bitter Lake Refuge, at Blue Spring in Eddy County, and in a few Texas localities (Bednarz 1975, Hubbard et al. 1979). Bednarz estimated that 33,500 individual gambusias existed in the Lake St. Francis area. Because there have been transplants, the current distribution of these and other fish in the RNA is not wholly natural (Bednarz 1975). Bednarz speculates that the failure of Pecos gambusia to become established in Lake St. Francis itself, though the water seems suitable, was predation by the green sunfish (*Lepomis cyanellus*).

The RNA also provides important habitat for the Pecos pupfish (*Cyprinodon pecosensis*), no longer listed as threatened because its habitats in the Pecos drainage seem, collectively, to be relatively secure (Bednarz 1975, Echelle and Echelle 1978, Hubbs and Echelle 1972, Kodric-Brown 1977).

Many terrestrial bird species nest in the area (USDI—Fish and Wildlife Serv. 1984), for instance great horned owls on the bank of Lake St. Francis. Desert cottontail, black-tailed jackrabbit, striped skunk, raccoon, bobcat, coyote, gray fox, badger, and long-tailed weasel are among the mammals noted for this part of the Refuge. Reffalt (1968), quoted at length by Potter (1974), lists many vertebrates known in the northern tract of Bitter Lake Refuge; probably nearly all are at least occasional visitors to Lake St. Francis.

Intrusions and Threats

Well-graded but lightly-traveled roads crisscross the research natural area: mainly 3 east-west roads across the north, south center, and south, a road along the whole east side, and a central road from the middle east-west road north to Lake St. Francis. Ditches several feet deep, with excavated earth mounded at their sides, connect the 30 largest sinks for the purpose of taking overflow to the Refuge impoundments; but water levels have been well below ditch levels for many years.

Figure 41. Alkali sacaton and a little saltgrass. Lake St. Francis RNA.

There has been a problem with swimmers trespassing in summer. Results are litter, disturbance of wildlife such as nesting owls, and roiling of water that can prevent breeding by minnows (letter from A. Kodric-Brown included in Ligon 1976).

Invasion by saltcedar and to a much lesser extent by Russian olive might be considered an intrusion. Some eradication of saltcedar has been attempted, but none is now planned.

Mineral rights to 360 acres of the RNA are owned by the state and the township is being explored for natural gas with some success. A similar situation led to a trespass road and drilling in the northern tract of the Refuge in 1982.

Most pressing, but perhaps politically intractable, is the problem of drying springs and ponds and increased salinity of groundwater that supplies surviving springs and ponds. A heavy rainstorm 70 miles west of Bitter Lake Refuge can raise water levels appreciably. An exceptional year of precipitation in the Hondo Basin, for instance 1941 with twice the normal amount, raised water levels 14 to 17 feet (Bean 1951, Mourant 1963). The usual story, however, is not up but down; even a general physiography text of 50 years ago (Fenneman 1931) noted the falling watertable of the Roswell Artesian Basin. The watertable in the recorder well closest to Lake St. Francis—6 miles southwest—declined 25 feet in 19 years, 1959–1977 (Hudson 1980). Mourant (1963) states that the decline of the watertable in the San Andres Formation—the region's principal aquifer—can be expected to continue at a rate of 1.5 to 2 feet per year if pumpage and recharge remain the same. But they have not remained the same; in the Pecos Basin water depletions for irrigated agriculture increased by 30,000 acre-feet per year, or 11%, during 1970–1980, and industrial-mineral use increased by 8,000 acre-feet, or 185%, during that period (Sorenson 1982). Clearly major values of the research natural area are in peril.

Research

Research on minnows in the RNA is mentioned above. The New Mexico Native Plant Society is studying changes in vegetation since the survey by Campbell (1937).

Maps

Topographic: U.S. Geological Survey 1:24,000 series, Bitter Lake Quadrangle, 1962, and 1:100,000 series, Roswell sheet, 1979. Geology: Kelley (1971). Vegetation: Campbell (1937). Soils: Hodson et al. (1980), but note that on Map Sheet 3 Lake St. Francis is the 2.6-mm.-diameter feature 5 cm. southwest of the feature *labeled* Lake St. Francis. Aerial photography: Hodson et al. (1980).

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USDI—Fish and Wildlife Serv. Birds of Bitter Lake National Wildlife Refuge [Pamphlet]. USDI—Fish & Wildlife Serv.; 1984. 2 p.

MATHERS RESEARCH NATURAL AREA

Shinnery vegetation anchors the sands of these 242 acres inhabited by lizards, prairie chicken, pronghorns, mule deer, and coyotes. Dominant plants are 2-foot-high shrubs, shin oak and sand sagebrush, and a 5-foot-high grass, sand bluestem. Livestock and vehicles are excluded from a 96-acre fenced area; the remaining acreage is open and grazed year-round.

Administration

Area Manager
Roswell Resource Area
Bureau of Land Management
1717 W. Second Street
P.O. Box 1397
Roswell, NM 88201 (505) 622–7670

Mathers RNA is in the East Chaves Planning Unit of the Roswell Resource Area of the Roswell District, Bureau of Land Management, U.S. Department of the Interior. Mathers Natural Area, a 362-acre tract, was so designated in August 1970. Part of the natural area was further designated a National Natural Landmark in May 1982. In September 1982 the 242 acres of national natural landmark were redesignated as Mathers RNA. The area is segregated from all forms of appropriation including mining and mineral leasing.

The 96-acre fenced area is managed for natural area and wildlife purposes; livestock and vehicles are excluded. The remaining acreage is unfenced. West of the fenced area an 86-acre tract is part of Allotment 5034 where, although grazing is permitted at an average density of 224 acres per cow year-round, actual use is light because of lack of water. Two smaller pieces of the RNA in other allotments are similarly managed. Prairie chicken, pronghorn antelope, and deer may be hunted in the whole research natural area.

Location and Access

Mathers Research Natural Area is in Chaves County, centered at lat. 33°28′40″ N., long. 103°49′30″ W., (fig. 42). in T. 10 S., R. 30 E., sec. 1 (NE1/4) and T. 10 S., R. 31 E., sec. 6 (W1/2 of NW1/4).

To reach Mathers from Roswell proceed 40 miles east on U.S. 380, thence from the roadside park 4.1 miles north on a graded road, where a cattle guard and east-west fence are just inside the natural area. The natural area is on both sides, 88% of it to the west, where a 96-acre fenced portion is adjacent to the county road. A bladed road (to a drilling pad) follows the north boundary of the natural area.

The nearest accommodations are in Tatum, 33 miles east of the roadside park, and in Roswell, 40 miles west. Campgrounds are in Bottomless Lakes State Park, off U.S. 380 southeast of Roswell.

Climate

Mathers is in a semi-arid, warm region, with mean temperature 59°F (15°C) and average precipitation 14 inches (356 mm.). The highest temperature recorded at Maljamar—42 miles south but similarly located in the Mescalero Sands—is 113°F (45°C), the lowest −10°F (−23°C). Climate is discussed by Davis (1979) and by Houghton (in Lenfesty 1983). Monthly data from Maljamar, about 150 feet lower than Mathers (Station Index No. 5370) are plotted in figure 43.

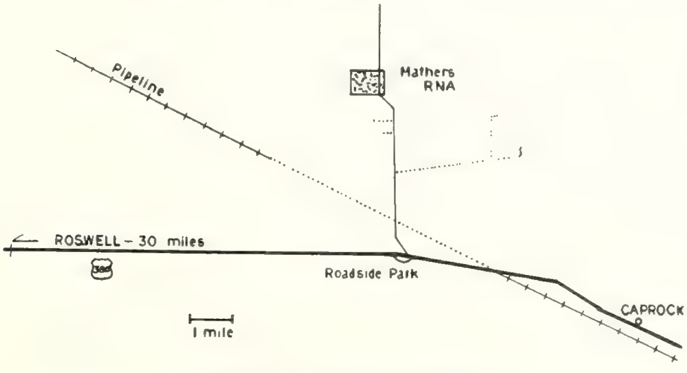

Figure 42. Mathers RNA.

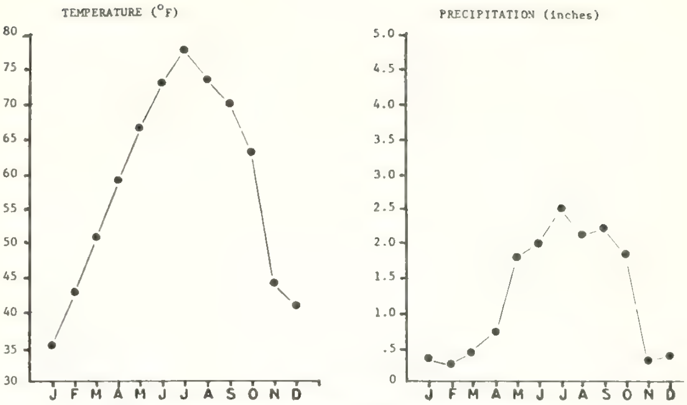

Figure 43. Climate of Mathers RNA.

Physiography, Geology, Soils

Mathers Research Natural Area is in the Mescalero Sands, which are at the eastern edge of the Pecos Valley section of the Great Plains Province (Fenneman 1931). Mathers lies 5 miles west of 200-foot-high Mescalero Ridge (or Caprock), which is here the western edge of the Llano Estacado in the High Plains section.

In the research natural area elevation varies only from 4,135 to 4,160 feet (1,260–1,268 m.), but landforms are nonetheless of interest. They include hummocks and stabilized dunes, and sand blow-outs to 8 feet deep and 35 feet or more across.

These surface deposits are Pleistocene and Recent alluvium. Bedrock—not exposed—includes Permian rocks of Guadalupian age and, below them, other Permian, Pennsylvanian, and Devonian strata. Though reef rocks of the Guadalupe Series are major oil and gas producers, exploration in the immediate vicinity of Mathers RNA is reported to have yielded only dry holes. Producing fields are several miles north, east, and south.

Lenfesty (1983) maps Mathers RNA as Roswell Jalmar fine sands and discusses characteristics of the several soils included. Principal types are Ustipsamment soils—yellowish, fine sand (fig. 44) over thick deposits of sand with caliche at 20–40 inches—and Haplargid soils in which sand over-lies thick sandy clay loam with a caliche layer at 4 to 6 feet. The caliche layer, often exposed by shifting sand, is discussed by Bretz and Horberg (1949).

Vegetation

Shinnery (French *chênerie*, from *chêne*, oak) covers large areas of western Texas and Oklahoma, and in New Mexico occupies some 3,000 square miles or 2% of the state (fig. 44). Grazing practices that have led to increase in mesquite (*Prosopis*) and mineral extraction—oil, gas, and phosphate—have left little of the shinnery intact. The Mathers area is relatively undisturbed (fig. 45). It might be argued that heavy grazing, aboriginally by bison, is a natural phenomenon.

Two-foot-high shinnery oak (*Quercus havardii*), sand sagebrush (*Artemisia filifolia*), and soapweed (*Yucca glauca*) are the only major shrubs. Diverse grasses, many of them rhizomatous, are in some instances two or three times as tall as the shrubs. Prominent are sand bluestem (*Andropogon hallii*, = *A. gerardii* var. *paucipilus*), little bluestem (*A. scoparium*, = *Schizachyrium scoparium* var. *neomexicanum*), giant dropseed (*Sporobolus giganteus*) and other dropseeds, fall witchgrass (*Leptoloma cognata*), gramas (*Bouteloua gracilis*, *B. eriopoda*, *B. curtipendula*, *B. hirsuta*), and three-awns (*Aristida longiseta* and *A. roemeriana*) (fig. 46). Forbs are also many, including several near their western limits. *Euphorbia geyeri*, *Phyllanthus abnormis*, *Stillingia sylvatica*, and *Asclepias arenaria* are among species limited to loose, sandy soils.

Davis et al. (1979) map the southeast edge of the RNA, outside the fence, as bearing shinnery subtypes that lack the abundant bluestem grasses of the remainder of the research area.

Shinnery oak has been represented continuously in the pollen profile of the Mescalero Sands for more than 3,000 years (Beckett 1976). Vegetation and flora of the Sands are described by Spellenberg (1979), Potter (1975), Davis et al. (1979), and Smith (1971).

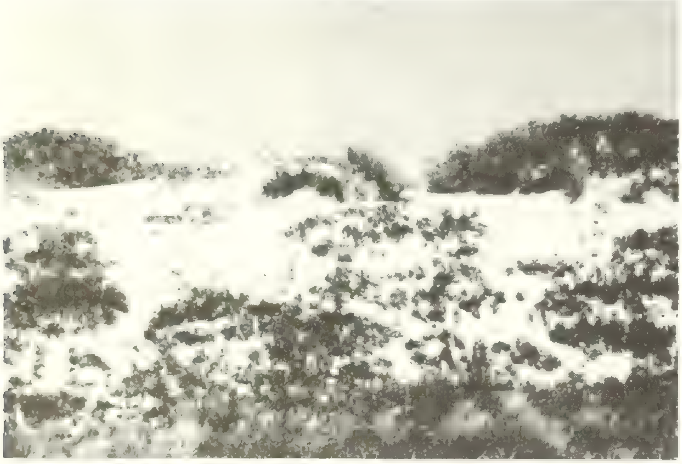

Figure 44. Shinnery oak holding a sand ridge. Mathers RNA. (Courtesy of J. C. Egbert.)

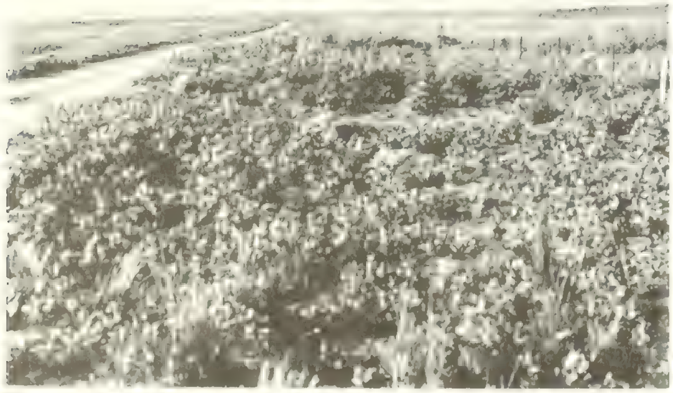

Figure 45. Shinnery between fenced area and county road. Mathers RNA. (From Potter 1975, courtesy of L. D. Potter.)

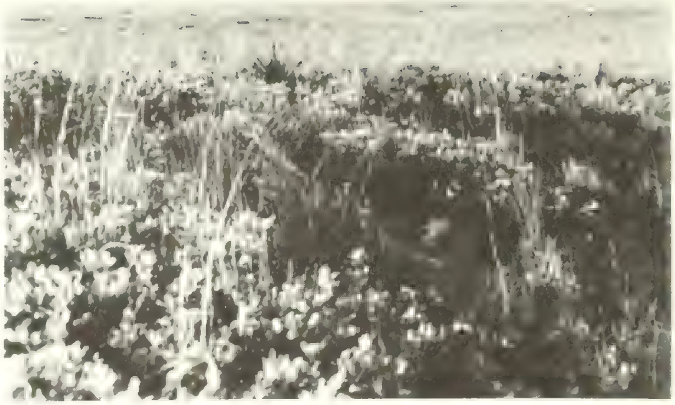

Figure 46. Shinnery oak and dropseed on well-anchored ridge. Mathers RNA. (From Potter 1975, courtesy of L. D. Potter.)

Küchler (1975), surprisingly, maps the vast acreage of southeastern New Mexican shinnery as potentially producing Grama-Buffalo Grass (his Type 65). His Type 71 (Shinnery) seems more appropriate, and Donart et al. (1978) include the Mescalero Sands in their Type Plb, Mixed Bluestem-Shinnery.

Animals

The shinnery is a highly productive ecosystem for a semi-arid region, and animals in considerable numbers and diversity inhabit the Mescalero Sands. Aside from domestic cattle the principal herbivorous mammals are mule deer, pronghorn antelope, blacktail jackrabbit, and a variety of rodents for which, however, there are no site-specific records. Elsewhere in the Sands and probably at Mathers are ground squirrels (*Citellus spilosoma*), kangaroo rats (*Dipodomys spectabilis* and *D. ordii*), pocket mouse (*Perognathys* sp.), woodrat (*Neotoma micropus*), harvest mouse (*Reithrodontomys* sp.), white-footed mice (*Peromyscus* spp.), and pocket gopher (*Geomys bursarius*) (Davis et al. 1979, Smith 1971). Bison remains are still found; this species may have had major influence on present vegetation of the Mescalero Sands. Even more recently departed is a race of white-tailed deer believed by Smith (1971) to be distinct; a few survived around the RNA at least until 1967, but the lone survivor reported in 1980 was well south of Mathers RNA.

Carnivores in the vicinity include prominently coyote, bobcat, foxes (*Vulpes velox*, *V. macrotis*, and *Urocyon cinereoargenteus*), skunk (*Mephitis mephitis*), and badger (*Taxidea taxus*).

Common reptiles in the natural area are desert side-blotched lizard (*Uta stansburiana*), lesser earless lizard (*Holbrookia maculata*), and the six-lined race-runner (*Cnemidophorus sexlineatus*). The endemic sand dune lizard (*Sceloporus graciosus arenicolous*) occurs nearby but Egbert (1979) thinks that the natural area itself provides only submarginal habitat. Several snakes are common including rattlesnakes (*Crotalus viridis, C. atrox*, and *Sistrurus catenatus*) and coachwhip (*Masticophis flagellum*).

Smith (1971) lists 70 bird species for the Mescalero Sands. Swainson's hawk, for instance, is a regular visitor to Mathers RNA, and several passerines nest in the shinnery. Of chief interest is the lesser prairie chicken, of which 3 nest sites were found by Davis et al. (1979) within the research natural area and 3 leks (booming grounds) near it. This species is restricted to scattered tracts of shinnery or sand sagebrush in the southern Plains states (Taylor and Guthery 1980). Although mainly insectivorous in summer, during other seasons prairie chickens depend heavily on acorns, catkins, and new leaves of shin oak (Davis et al. 1979). Nesting sites are related to abundance and height of grass; heavily grazed land is unfavorable (Davis et al. 1979).

Archaeology

The Mescalero Sands are rich in human artifacts that extend from 11,000 years ago (rare Clovis points) to recent use by Comanches and Apaches. Hunting of big game including mammoths and an extinct bison species attracted early visitors. In the Formative state (950–1450 A.D.) the large acorns of shin oak were a major attraction (Beckett 1975).

Intrusions and Threats

The graded road sustains moderate traffic, mostly petroleum-related, through the east side of Mathers Research Natural Area. Two short fences in addition to that protecting 96 acres of the area are near the south edge of the RNA. A watering device for small wildlife is in the northeast part of the fenced area. Drilling pads and other oil and gas development are near the natural area. Man—usually as a hunter of prairie chickens—and cattle visit this easily accessible area.

Research

Bureau of Land Management personnel collected baseline data on vegetation of the area in 1968. Considerable research has been done on prairie chickens and white-tailed deer of the Mescalero Sands (for instance Davis et al. 1979 and Smith 1971), but none seems to relate to Mathers RNA specifically. To map the RNA onto Davis' figure 11, draw a rectangle such that Nest Site 39 falls just north of the northwest corner and Lek 22 just east of the southeast corner.

Maps

Topographic: U.S. Geological Survey 1:24,000 series Mescalero Point NE Quadrangle. A variety of maps relating to soils, vegetation, grazing allotments, and range improvements is included in USDI BLM (1979b), and see further administrative maps at the Roswell office of the Bureau. Soil and aerial photography: Lenfesty (1983).

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MAXWELL RESEARCH NATURAL AREA

This seldom-dry playa lake on the plains of the upper Canadian River provides Canada goose and other waterfowl habitat. Alkali sacaton and small areas of wheatgrass-bluegrama-buffalo grass surround the lake.

Administration

Refuge Manager
Maxwell National Wildlife Refuge
P.O. Box 276
Maxwell, NM 87728 (505) 375-2331

The 3,270-acre Refuge was established in 1966; a unit of the National Wildlife Refuge System, it is administered by the Fish and Wildlife Service of the U.S. Department of the Interior. The former croplands were purchased in 1965 to restore Canada goose and duck habitat. A brief summary of the complex history of the Maxwell area is given by Lessard (1976). The 80-acre (32-hectare) RNA was designated August 17, 1973. The 235 acres immediately east of the RNA (but not, strangely, the RNA itself) have been recommended as a national natural landmark (Potter 1975).

The RNA is open to hiking but closed to all hunting. It is closed to livestock grazing, and has probably not been grazed since 1965. The west boundary is "indented" at one point to make room for a neighbor's dirt stock tank, but the fence is good here and on the south boundary. An old fence with breaks in it is along the east side of the RNA, and swings east of the boundary to include the southeast end of the lake, an extra acre or so.

Location and Access

Maxwell Research Natural Area is in Colfax County, centered at lat. 36°33′15″ N., long. 104°36′10″ W., (fig. 47). These 80 acres are in T. 27 N., R. 22 E., sec. 21 (W1/2 of the SE1/4), in the southwest corner of Maxwell National Wildlife Refuge.

To reach the natural area leave Interstate 25 at Maxwell, take the main street (Old U.S. 85) north 0.8 miles, turn west on N.M. 505, and from that point proceed 3.25 miles west, where the RNA is immediately north of the highway right-of-way. The Refuge entrance is 2.5 miles from that same turn, then north 1.25 miles to headquarters.

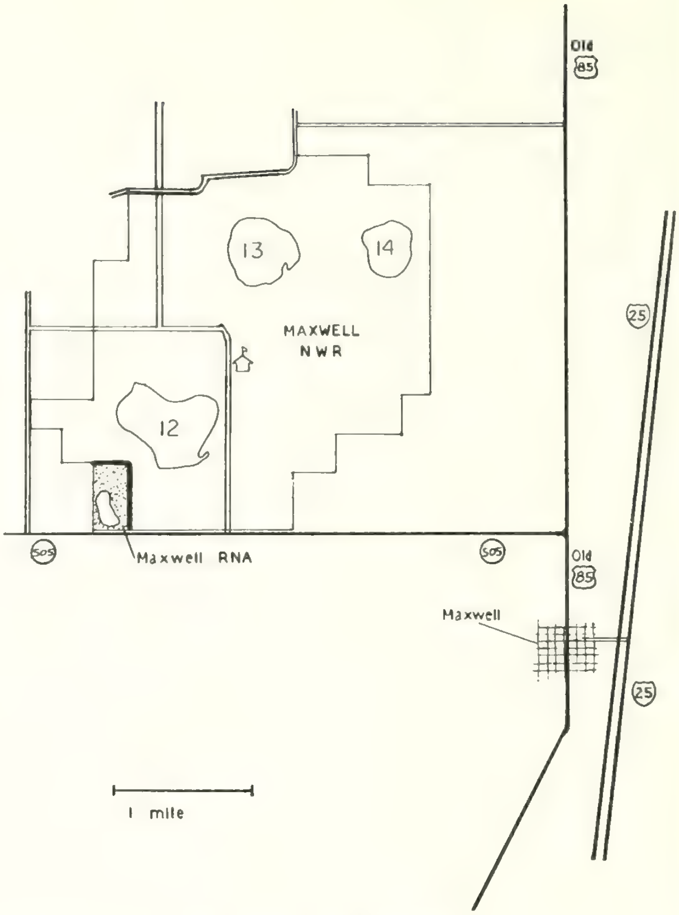

Figure 47. Maxwell RNA.

Nearest motels are in Springer, 17 miles south, and Raton, 26 miles north. There is no camping in the Refuge and no public land nearby.

Climate

This is a cool area with a ustic moisture regime. The mean temperature is 44°F (7°C) and the average precipitation 15.6 inches (396 mm.) per year. The record temperatures at Maxwell are 100°F (38°C) and -29°F (-36°C). Climate is discussed by Houghton (in Anderson et al. 1982) and by Griggs (1948), who gives data from the Maxwell weather station through 1940. Monthly averages from Springer, 14 miles to the south are graphed in figure 48.

Physiography, Geology, Soils

Maxwell is on the Las Vegas Plateau in the Raton section of the Great Plains Province. This part of the Las Vegas Plateau is no plateau, but rather the broad valley of the Canadian River and its tributary the Vermejo

River, which are 3.8 miles east and 2.6 miles south of the RNA, respectively. The land is flat, with mesas (plateau remnants) visible a few miles away especially to the northwest, where the higher Park Plateau meets the Las Vegas Plateau. The Sangre de Cristo Mountains are visible 25 miles to the west. Elevation in the RNA is from about 5,995 (1,827 m.) to 6,012 feet (1,832 m.).

A shallow lake—a playa lake typical of the area—occupies up to 25 acres or more of the natural area, varying in size seasonally and from year to year. Unlike other lakes on the Refuge, this is wholly a natural depression. Since 1966 it has been dry once, 1977, and completely full twice, 1968 and 1974. In late 1982 it covered perhaps 18–20 acres. Water—perhaps merely shallow run-off of irrigation water from nearby fields and canals—seeps in from the west side.

The northeastern 15 acres of the natural area are not part of the lake depression but a plateau raised a few feet above it. An irrigation ditch runs near the edge of the plateau.

Soil of the raised corner of the RNA is Swastika silty loam, with topsoil more than 4 inches deep and a 26-inch subsoil of silty clay. This is a mixed, mesic, aridic Argiustoll. Next south from this plateau, and also in the southwestern corner of the area, is Vermejo silty clay loam, characterized by a thin silty clay topsoil, a 16-inch silty clay subsoil, and a substratum containing salt crystals. It is a fine, mixed, mesic, ustic Torriorthent. The playa, mapped to include about 50 acres, contains an eroded combination of Swastika and Vermejo soils without their topsoils (Anderson et al. 1982).

Underlying strata are Upper Cretaceous: the Smoky Hill Marl member of the Niobrara Formation and the Pierre Shale, undifferentiated (Griggs 1948). No bedrock is exposed in the research natural area.

Vegetation

The upland 15 acres of Swastika loam have the Grama-Buffalo Grass Association (Küchler's Type 65) listed for the RNA (fig. 49). Western wheatgrass (*Agropyron smithii*), galleta (*Hilaria jamesii*), ring muhly (*Muhlenbergia torreyi*), wildrye (*Elymus canadensis*) and sand dropseed (*Sporobolus cryptandrus*) as well as the named dominants (*Bouteloua gracilis* and *Buchloe dactyloides*) are present.

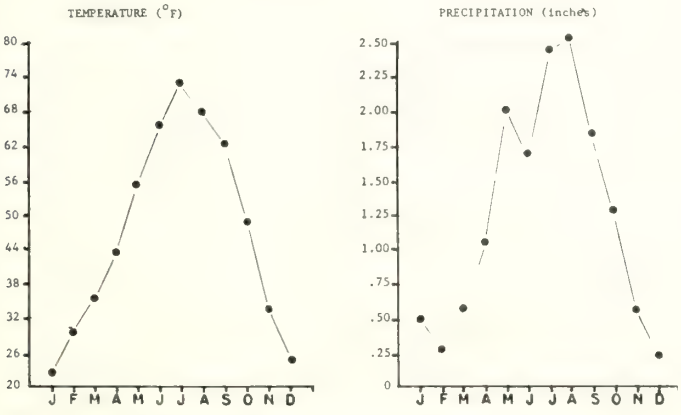

Figure 48. Climate of Maxwell RNA.

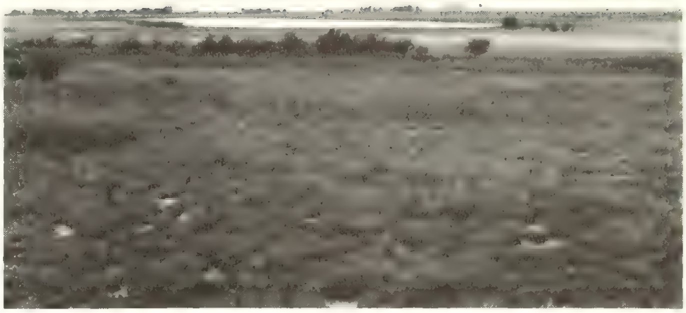

Figure 49. Buffalo grass and gramas in foreground; rabbitbrush in mid-ground; saltcedars by lake. Maxwell RNA.

On disturbed earth next to the irrigation canal are several annual, non-native weeds. On the "breaks"—the slight declivity—are rabbitbrush (*Chrysothamnus nauseosus* var. *graveolens*), soapweed (*Yucca glauca*), and some of the grasses just mentioned.

Most of the natural area is covered by alkali sacaton (*Sporobolus airoides*) with some saltgrass (*Distlichis spicata*) and chenopodiaceous forbs between the sacaton hummocks (fig. 50). The west, wettest side of the pond has mainly sacaton but with a thicket of other grasses (prominently scratchgrass, *Muhlenbergia asperifolia*) and forbs such as *Conyza*. Toward the southwest corner some species listed above for the upland appear again.

The dry, crusty playa edge supports seepweed (*Suaeda*) and other fleshy-leaved forbs. One large and several small saltcedars were growing at the north end of the pond in 1982. The pond supports a mat formed by an unidentified filamentous alga.

Potter (1975) lists plants for an area adjacent to the RNA, many of them also in the natural area.

Animals

Several thousand Canada geese winter at the Maxwell Refuge. About 15 species of ducks use the Refuge, and 5 of them—mallard, gadwall, pintail, green-winged teal, and blue-winged teal—are recorded as breeding here commonly, while geese and cinnamon teal do so occasionally (USDI—Fish and Wildlife Serv. 1972) (fig. 51). Marsh hawk, kestrel, scaled quail, ring-necked pheasant, killdeer, avocet, mourning dove, roadrunner, barn owl, great horned owl, burrowing owl, nighthawk, rufous hummingbird, flicker, red-headed woodpecker, and 25 songbird species were also listed as nesting at the Refuge, of a total list (written after 5 seasons of Refuge operation) of 153 bird species. Sandhill crane, snowy egret, great blue heron, black-crowned night heron, white-faced ibis, white pelican, and double-crested cormorant are seen at various times of year. Golden eagles nest regularly nearby, on the Vermejo River, and bald eagle sightings—now mainly restricted to fall and winter in New Mexico—here continue occasionally through summer. Presumably all these bird species use the natural lake in Maxwell RNA as well as the Refuge's larger impoundments, which have fishermen and picnickers.

Coyote, bobcat, raccoon, striped skunk, cottontail, jackrabbit, various bats, *Perognathus* and *Peromyscus* species, and a variety of other rodents are here.

Intrusions and Threats

An irrigation ditch and disturbed ground next to it, including a 2-track road, cross the northern part of the RNA. A lightly traveled state highway, with utility lines along it, is immediately south of the natural area, and a stock tank and cultivated fields are to the west. Planted trees that surrounded a farmhouse (now gone) are just outside the northwest corner of the RNA.

An 1,825-foot-deep test well to the Dakota Sandstone 3 miles west of the RNA produced no oil or gas.

Research

None is known.

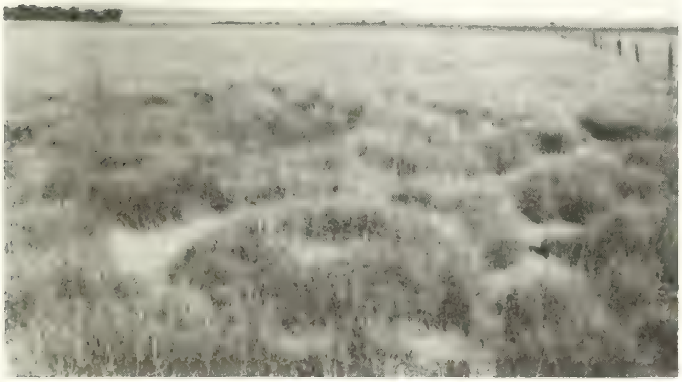

Figure 50. Alkali sacaton. Trees are just outside the northwest corner of Maxwell RNA.

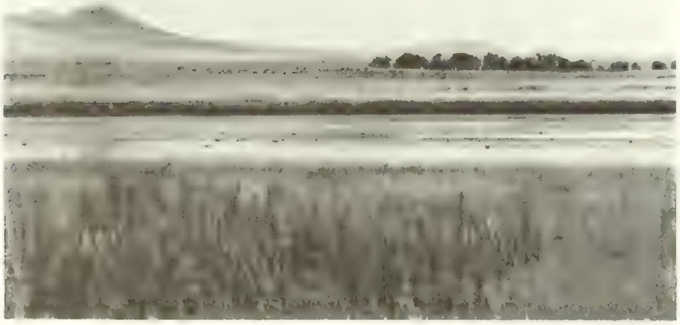

Figure 51. The lake, with ducks and algae. Maxwell RNA.

Maps

General: management maps are at Refuge headquarters and in USDI—Fish and Wildlife Serv. (1968) and in Potter (1975). Topographic: USDI—Geological Survey 1:24,000 series, Maxwell Quadrangle, 1971, and 1:100,000 series, Raton sheet, 1981. Geology: Griggs (1948). Soils: Anderson et al. (1982) and Potter (1975). Aerial photography: Anderson et al. (1982).

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MONUMENT CANYON RESEARCH NATURAL AREA

Ponderosa pine with scattered southwestern white pine covers most of these 640 acres in the volcanic Jemez Mountains. Some white fir and Douglas-fir occur in groups, and the latter species dominates the steep north-facing escarpment in the area's northwest corner. Bandelier Tuff is exposed in the walls of small canyons and forms sharp 60-foot spires and columns in the northwest.

Administration

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Santa Fe National Forest
P.O. Box 1689
Santa Fe, NM 87501 (505) 988–6940

Director
Rocky Mountain Forest and Range Experiment Station
240 West Prospect
Fort Collins, CO 80526 (303) 221-4390

A "Cooperative Agreement Between the Department of Agriculture and the University of New Mexico for the Purpose of Research and Observation in Certain Natural Sciences" was signed in May 1930 by the President of the University and the Secretary of Agriculture covering 18 sections (11,520 acres) including the present RNA. In October 1932 the Regional Forester and the experiment station Director further designated one of the 18 sections—T. 18 N., R. 3E., sec. 9—as Monument Canyon Natural Area, and specified that neither live nor dead timber should be cut there. "No occupancy of any kind should be permitted. Conservative grazing may continue, but overgrazing must be avoided" on the 640 acres (259 hectares). Management of Section 9 as a natural area has been confirmed from time to time, most recently in the draft Santa Fe National Forest Plan. Timber cutting and other alterations on the other 17 sections covered by the cooperative agreement were to be restricted to such as the Chief Forester might permit, to contribute to study uses of the natural area.

In 1932 the allotment permitted 8 cows year-long on the 640 acres, which would be 32 cows for a 3-month season. It is not likely that grazing that heavy is occurring. In late 1982 no signs of recent livestock use were seen.

Mineral entry has not been prohibited, but mineral values are unlikely here. Hunting is permitted. There are no fences except at the head of a trail down the escarpment. The whole section is well posted as a research natural area (the only one in New Mexico so marked), but firewood cutting is the only activity explicitly prohibited on signs. Off-road vehicle maps show that the area is closed.

A goal expressed for the natural area (USDA—Forest Service 1982), "Maximum tolerable loss from wildfire objective is 10 acres," is probably unobtainable, should a fire start. See under "Intrusions and Threats," below. Because of easy access and abundant fuelwood the area is difficult to administer as a natural area.

Location and Access

Monument Canyon Research Natural Area is in northern Sandoval County, centered at lat. 35°48′20″ N., long. 106°37′30″ W., (fig. 52). It is sec. 9 of T. 18 N., R. 3 E.

To reach Monument Canyon from Los Alamos go south and west on N.M. 4 for 21 miles, then south on Forest Road 10 (a sign to Ponderosa is at the junction) for 2.4 miles, then west on Forest Road 135. The RNA is well signed beginning 1.2 miles from the latter turnoff. Road 135 wanders for 1.8 miles through the natural area.

The RNA may also be reached from the south: turn north from N.M. 44 on N.M. 4 at San Ysidro. The shorter but rougher route turns east on N.M. 290, 6 miles from San Ysidro; go through Ponderosa where the main road continuing is Forest Road 10; be careful to stay on Road 10 through junctions at Paliza Campground, and from there go about 8 more miles to the turn west on Forest Road 135. Smoother but longer is to stay on N.M. 4 from San Ysidro to its northern junction with Forest Road 10, 7 or 8 miles after La Cueva, as described above.

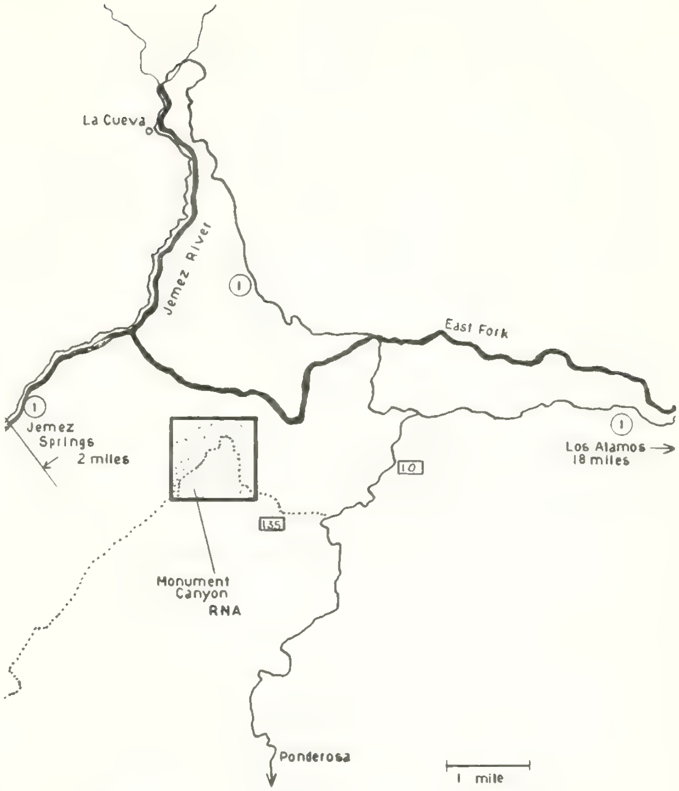

Figure 52. Monument Canyon RNA.

There are campgrounds at Paliza and La Cueva and at Las Conchas, 4 miles east of the northern Forest Road 10 turn-off; and camping is generally permitted throughout the national forest. There are motels in Los Alamos.

Climate

At 8,200 feet elevation, the area is quite cool and moist. The nearest weather station, at Jemez Springs, is only 3.5 miles southwest but is 2,000 feet lower than the RNA. From the mean temperature of 50°F (10°C) in Jemez Springs should be subtracted about 10°F (5°C), and to the average annual precipitation there of 16.4 inches (417 mm.) should be added about 7 inches (178 mm.) to represent the RNA (Tuan et al. 1973). The maximum rainfall expected within a 24-hour period, once in 2 years, is 1.7 inches.

Discussion or data relevant to the area are given by Griggs (1964) and Maker et al. (1971). Monthly distributions of average temperature and precipitation at Jemez Springs (Station 4369) are graphed in figure 53.

Physiography, Geology, Soils

The young, volcanic Jemez Mountains are a southern extension of the San Juan Mountains of Colorado-New

Mexico, and thus for most authors belong to the Southern Rocky Mountain Province. Fenneman (1931), though doubtful, agreed; Griggs (1964) puts the border between Southern Rocky Mountain and Basin and Range Provinces through Monument Canyon RNA.

The Jemez Mountains rise to 11,560 feet; Redondo Peak at 11,254 feet is 5 miles northeast of the natural area. Redondo Peak is a volcanic core within Valles Caldera, a 15-mile-diameter collapsed volcanic dome. The caldera held a lake in late Pleistocene time. When lake waters escaped to the southwest, probably by overtopping and cutting the lip of the caldera, they sliced deep canyons. The deepest, a mile west of the RNA, is Cañon de San Diego, 2 miles wide and 1,500 feet deep. Monument Canyon (canyon of the East Fork of the Jemez River) is about 1,200 feet deep at the north edge of the natural area; it joins Cañon de San Diego a mile to the northwest.

Except for about 120 acres of north-facing escarpment, the natural area is on the slightly dissected Jemez Plateau. The height-of-land runs very close to the escarpment at 8,310 to 8,536 feet (2,533 to 2,602 m.) elevation. From that divide 80% of the RNA drains southwestward through ephemeral streams, Church Creek and Cañon de la Cañada, to the Jemez River, with a low point of 8,145 feet (2,483 m.) where the Cañada leaves the southwest corner of the RNA. The much steeper northern escarpment drops with a slope of 50–60% from the ridge at 8,536 feet to the area's lowest point at 7,720 feet (2,353 m.) in the northeast corner. This declivity continues northward from the RNA to the East Fork of the Jemez at 7,250 feet elevation.

The natural area is fairly flat except near streams; these have cut several 50-foot-deep canyons, and a 200-foot wall stands beside the Cañada where it leaves the RNA.

There is no permanent water in the natural area.

The Jemez volcanic field straddles the western margin of the Rio Grande rift and consists of a thick pile of Pliocene and Quaternary extrusive rocks: the present elevation of the Jemez Mountains is due to this accumulation of volcanic rocks rather than to structural uplift (Griggs 1964, Woodward and Ingersoll 1979). Finally in mid-Pleistocene time volcanism was climaxed by two gigantic outbursts which produced the Bandelier Tuff (Smith and Bailey 1968), of which the Otowi Member covers most of the RNA (fig. 54). In eastern parts of the RNA some of the El Cajete Member of the late Pleistocene Valles Rhyolite is mapped by Smith et al. (1970). Griggs (1964) describes these formations. In the RNA Otowi rocks crop out along stream canyons and at the lip of the northern cliffs. Handsome 60-foot-high sharp spines and boulder-topped columns are found in the north-draining canyon at the northern point on Forest Road 135.

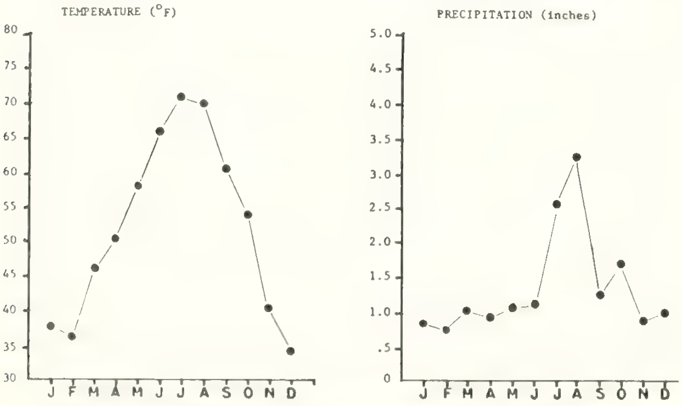

Figure 53. Climate of Monument Canyon RNA.

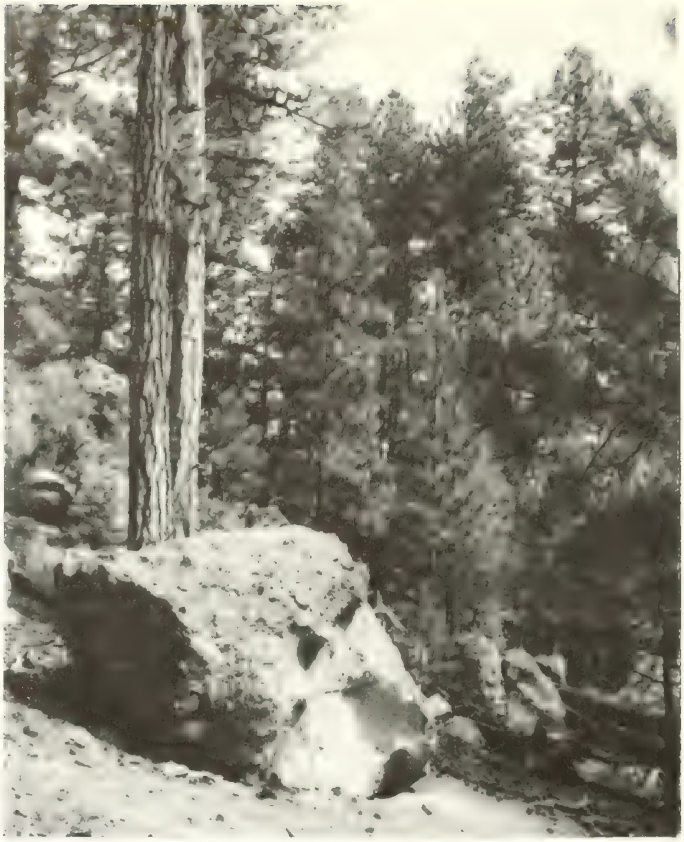

Figure 54. Ponderosa pine and a tuff boulder. Monument Canyon RNA.

Soils are classified by Maker et al. (1971) as Haploborolls and fine-loamy, typic Eutroboralfs. These authors describe several "mountain soils forming in igneous materials" without assigning them to associations. A more detailed soil survey is scheduled for publication by USDA—Soil Conservation Service.

Vegetation

Descriptions of the natural area in Forest Service documents list vegetation types as 590 acres of Interior Ponderosa Pine (Type 237), 36 acres of Interior Douglas-Fir (Type 20), and 14 acres brush; or, alternatively, 570 acres of commercial sawtimber and 70 acres "inaccessible." In 1943 volume was estimated at 85,000 board feet per acre. At some time average age, height, and diameter of both ponderosa pine and Douglas-fir were given as 125 years, 65 feet, and 22 inches. It is not clear what sort of averages these were. Dominant ponderosa pines in overmature stands are now 20–30 inches in diameter, but because there are hundreds of thousands of 2–4-inch-diameter trees in stagnated stands the average for all pines (pole height or greater) would still be much less than 22 inches.

At any rate Interior Ponderosa Pine does cover more than 80% of the natural area. A few stands are thrifty but most are either overmature or stagnated with 8,000 stems or more per acre. Dwarf mistletoe (*Arceuthobium vaginatum*) infection stunts growth of pine in some areas, and Douglas-fir is also infected by its dwarf mistletoe parasite. The fuel load is enormous, composed of litter and dead trees both down and standing (fig. 55).

Two associates of ponderosa pine here are southwestern white pines scattered singly throughout and clumps of mixed conifers (mainly white fir and Douglas-fir), usually by streams or on north slopes. Rocky Mountain junipers occur on rocky sites, and canyon slopes also have ocean spray (*Holodiscus*), mountain mahogany (*Cercocarpus*), locust (*Robinia*), Apache plume (*Fallugia*), wax currant (*Ribes*), mockorange (*Philadelphus*), and, by far the most prominent, Gambel oak (*Quercus gambelii*). Upland grasses include Arizona fescue (*Festuca arizonica*), mountain muhly (*Muhlenbergia montana*), pine dropseed (*Blepharoneuron tricholepis*), and squirreltail (*Sitanion hystrix* = *Elymus longifolius*), but grasses are abundant only in occasional forest openings.

On about 120 acres of the escarpment is a mixed conifer stand of the species listed for Type 210 in the Southwest (Eyre 1980) (fig. 56): Douglas-fir with white fir a prominent associate, plus southwestern white pine, ponderosa pine, aspen, and Gambel oak.

Deichmann (1980) surveyed vegetation of the RNA and reported 43 plant species, which he grouped in 5 communities: *Pinus ponderosa* dense dog-hair stands, *Pinus ponderosa* open mature stands, *Pinus ponderosa*-mixed conifer associations, *Quercus* associations, and *Cercocarpus* associations. The latter 2 types have important grass components: mountain muhly and sheep fescue (*Festuca ovina*) with the *Quercus* associations and mountain muhly and blue grama (*Bouteloua gracilis*) with *Cercocarpus*. Good photographs of vegetation are provided by Deichmann (1980) and McCallum (1980).

Animals

Mammals have not been studied in the RNA. Bear and deer sign are occasional in draws and common on the escarpment. Tassel-eared squirrels are frequently seen. Presumably the fauna typical of southwestern ponderosa pine forests is present. Studies of mammals northeast of Monument Canyon are reported by Swickard et al. (1971), and eastward in Bandelier National Monument by Guthrie and Large (1980).

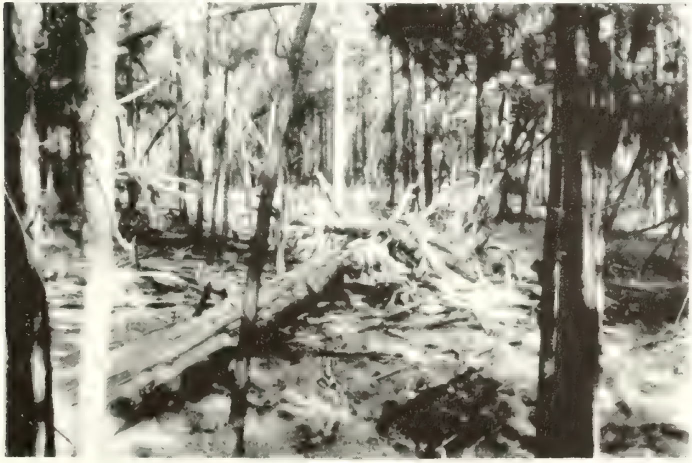
Figure 55. Ponderosa pine fuel. Monument Canyon RNA.

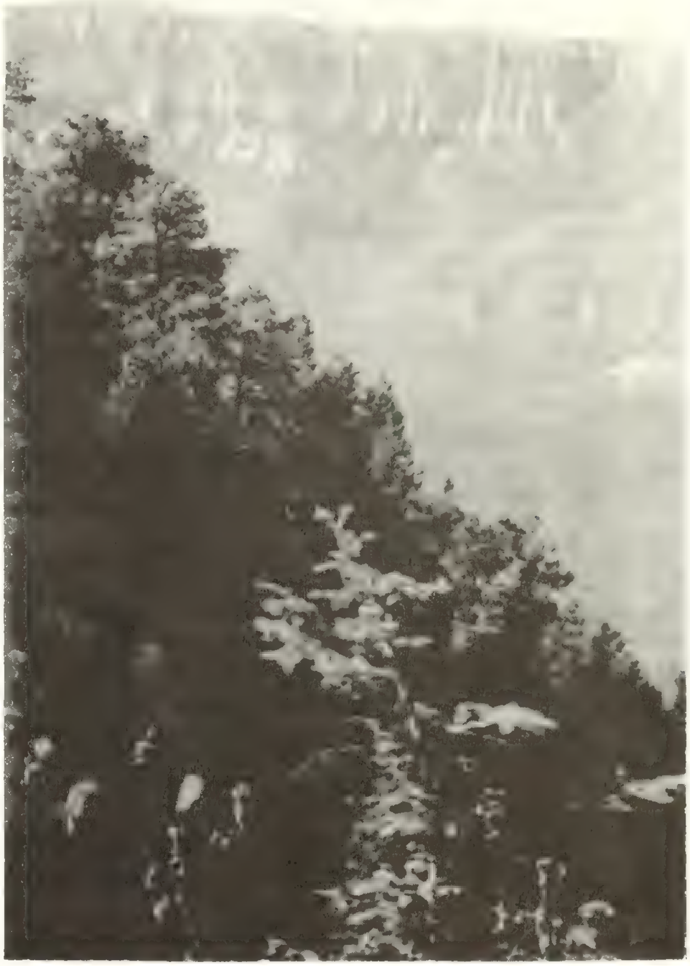
Figure 56. The northwestern escarpment. Ponderosa pine and Douglas fir. Rock pedestals. Canon de San Diego in background.

Bird ecology in the RNA has been studied in some detail by McCallum (1980), who sighted 47 species and gives a longer hypothetical list. Prominent in the RNA are band-tailed pigeon, flammulated owl, saw-whet owl, common nighthawk, white-throated swift, broad-tailed hummingbird, 5 woodpecker species, 5 flycatcher species, violet-green swallow, 4 corvid species, nuthatches, brown creeper, 3 warblers (especially Grace's warbler), and 4 fringillids (especially gray-headed junco). In 1982 turkey sign was occasional in the RNA.

The Jemez Mountain salamander (*Plethodon neomexicanus*) may be in the natural area on the escarpment. It is known 4 miles east and also 4 miles north, and habitat here seems suitable. The salamander is narrowly endemic: its total known distribution extends only about 18 miles east-west. New Mexico lists the species as threatened. For salamander biology see Stebbins and Riemer (1950), Reagan (1972), and Hubbard et al. (1979).

Intrusions and Threats

The Forest Service has from time to time reconsidered the suitability of Monument Canyon as an RNA because, being so accessible, it is difficult to protect. Firewood cutting in the area has been notorious; see, for instance, the Albuquerque Journal for 23 August 1974 on cutting in the RNA.

At least 5 roads are in the RNA. (1) Forest Road 135, while graded only occasionally, is passable for passenger cars. It leads to firewood areas and former timber-harvest areas west of the RNA. In its 1.8-mile passage through the RNA from the east it swings north close to the most scenic vistas, then southwest along the west rim of Cañon de la Cañada. (2) A road, formerly graded, connecting with Forest Road 135 near its northern curve and running the length of the bottom of Cañon de la Cañada. An attempt has been made to block it with earth at both ends, but this has not been completely effective. The road is revegetating slowly. (3) A short spur from the northern tip of Road 135 leading to a scenic overlook. Nothing on the ground indicates that this 2-track road is off limits. (4) A pack trail that once crossed the RNA a little south of the escarpment and, starting near the head of Cañon de la Cañada, descended the escarpment to the northeast. This was the Jemez Springs-Vallecitos de los Indios trail. The only part still conspicuous is the constructed section that runs from Forest Road 135 down the escarpment. Its entrance is fenced and gated. (5) Short logging spur roads, especially one in the west center of the RNA that branches from Forest Road 135. These are revegetating.

Cattle grazing seems to be a very minor intrusion. Grass composition and condition were excellent in 1982, given that this is a forest area without much grass.

The general area is rich in geothermal resources, but topography suggests that the RNA is not subject to development.

The principal threat appears to be fire. This has been recognized for decades by the Forest Service, and currently so in the Santa Fe Forest Plan. The situation is unnatural, resulting from control of normal wildfires that would have reduced fuel load. A fire during dry conditions could quickly destroy all the ponderosa pine here. Relevant research from a nearby area is reported by Foxx and Potter (1978).

Research

The Forest Service has sponsored botanical and ornithological studies of the RNA (Deichmann 1980, McCallum 1980).

Maps

General: USDA—Forest Service 0.5-inch-to-1-mile series, Santa Fe National Forest, 1975; and administrative maps. Topographic: USDI—Geological Survey 1:62,500 series, Jemez Springs Quadrangle, 1952,; 1:24,000 series, Jemez Springs Quadrangle, 1976, and Redondo Peak Quadrangle, 1977. Geology: Smith et al. (1970). Aerial photography can be inspected at Santa Fe or Jemez Springs; standard black-and-white print #106 can be ordered from the Aerial Photography Field Office, ASCS-USDA, Salt Lake City.

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RIO GRANDE MARSH RESEARCH NATURAL AREA

A narrow marsh and oxbow lake in the Rio Grande floodplain provide habitat for waterfowl and shorebirds and a feeding site for bald eagles and other raptors. Water levels are artificially managed. Tule marsh vegetation, abundant saltcedar, a few cottonwoods, and desert shrub occupy the 97-acre site.

Administration

Refuge Manager
Bosque del Apache National Wildlife Refuge
P.O. Box 1246
Socorro, NM 87801 (505) 835–1828

Rio Grande Marsh in one of 5 natural areas in the Bosque del Apache Refuge, a 57,191-acre unit of the National Wildlife Refuge System administered by the Fish and Wildlife Service, U.S. Department of the Interior. The Refuge was established in 1939. These 97 acres (39 hectares) were designated a research natural area August 17, 1973.

Access is allowed during daylight hours. Hunting is not allowed in the RNA. Fishing is allowed on the east side of the lake from late May through September. Grazing is not permitted, but there is evidence of trespass grazing between N.M. 1 and the marsh.

Another, larger part of the oxbow lake is just south of the RNA. Public access to it is forbidden. Hence this 50-acre area is better protected than the research natural area itself.

Location and Access

Rio Grande Marsh Research Natural Area is in Socorro County, centered near lat. 33°46′30″ N., long. 106°54′W., (fig. 57). It extends along N.M. 1 from 33°46′ to about lat. 33°47′22″ N. The north boundary is an east-west dike 0.4 miles long; it is the southern of two such neighboring dikes. The south boundary is a dike topped by a road that runs northeast from a point near N.M. 1, about 200 yards north of a railroad crossing. The east boundary is a graded Refuge road. Only the west boundary—N.M. 1—is fenced. Were the area surveyed it would be near the east edge of T. 6 S., R. 1 W.

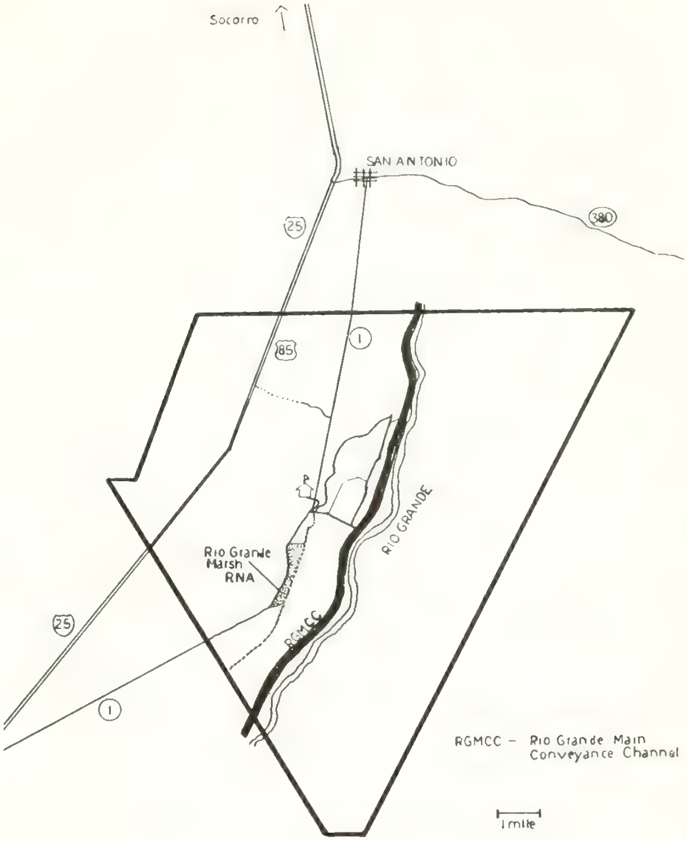

Figure 57. Rio Grande Marsh RNA.

Rio Grande Marsh is 19 miles south of Socorro and 132 miles north of Las Cruces. From the north turn off Interstate 25 for San Antonio; from the town of San Antonio follow Refuge signs 8 miles south on N.M. 1 to headquarters of Bosque del Apache Refuge; the RNA begins another 1.1 miles south of headquarters. From the south turn off for San Marcial and follow N.M. 1 northeast for 6.6 miles to the Refuge boundary and another 1.8 miles to the south edge of the RNA; Refuge headquarters are another 3 miles north. The west side of the RNA lies along N.M. 1. Access to the oxbow lake is easier, however, from the east side: enter the tour loop from headquarters and go south; continue straight where the main route turns left across a canal, and follow the road to its southern end at the RNA.

Accommodations are available in Socorro, 20 miles north.

Climate

Campbell and Dick-Peddie (1964), Houghton (p. 7–9 in Maker et al. 1972), and Poulsen and Fitzpatrick (1931) discuss climate of the area. Data from Refuge headquarters, a mile north of Rio Grande Marsh and a few feet higher, are given in figure 7 under Apache Camp Research Natural Area.

Physiography, Geology, Soils

The area is within the Basin and Range Province, which the Rio Grande here traverses in a rift valley (Hawley 1978). The natural area is in the Rio Grande floodplain and has been subject over the centuries to floods and to changes in the river's course. The only detailed soil map available (Poulsen and Fitzpatrick 1931), from an early 1929 survey, was largely outdated in August 1929 by a devastating flood that buried or washed away nearby towns such as Val Verde, 3 miles downstream. In 1929 the Rio Grande reached the southeast corner of what is now Rio Grande Marsh RNA; the river is now 1.5 miles east. The locality of the natural area is shown as partly marsh and oxbow lake in 1929, alkaline but less so than nearby parts of the floodplain (Poulsen and Fitzpatrick 1931).

Elevation is just under 4,500 feet (1,371 m.) in wet parts of the RNA, rising to 4,520 feet (1,378 m.) along N.M. 1. Three usually dry washes enter under N.M. 1 from the highlands to the west.

Distribution of marsh versus lake is controlled artificially within a narrow range, with a goal of maintaining the present mix of wetland habitats. Aerial photographs in 1972 show the area wetter than the 1929 survey, about 20% water, 40% marsh, and 40% land. There may be more pond and less marsh than this under current management.

No bedrock is exposed in the natural area.

The Gila-Vinton-Glendale soil association (Maker et al. 1972) is probably represented here mainly by Gila soils, particularly Gila clay on the west side, and Gila loam. Riverwash and Alluvial Land are also present. Soils are classified as Torrifluvents, Calciothids, and Torriorthents.

Vegetation

The east side of the RNA comprises ponds and tule marshes, and the latter reach the west side in the narrow (900-foot) central part of the research natural area. Dominants are cattail (*Typha*) and bulrush (*Scirpus validus*) with areas of saltgrass (*Distichlis spicata*), fig. 58. Next to the water are willows (*Salix exigua*) and saltcedar (*Tamarix*) forming an almost unbroken border along the west side of the wet area.

Dry soils—some clay, some sand—in the northwest and southwest corners of the RNA support about 40 acres of desert shrubs, primarily broom pea (*Psorothamnus* or *Dalea scoparia*), four-wing saltbush (*Atriplex canescens*), shadscale (*A. confertifolia*), and mesquite (*Prosopis glandulosa*), with scattered juniper (*Juniperus monosperma*) and, nearer the water, cottonwood (*Populus wislizenii*). Dropseeds including giant dropseed (*Sporobolus giganteus*) are conspicuous in sandy areas.

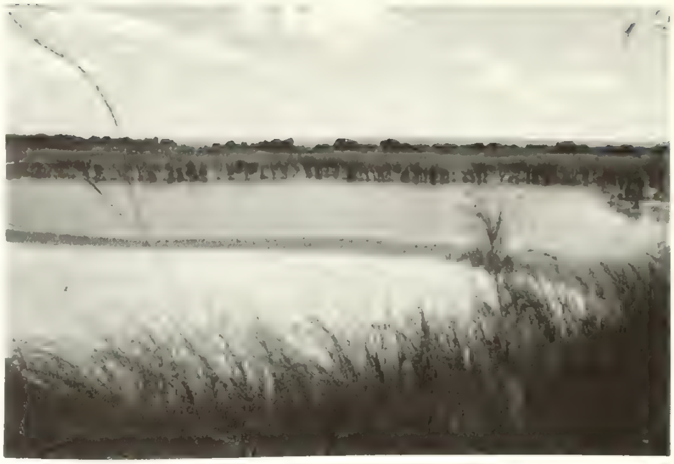

Figure 58. Bulrushes, mud, lake, marsh. Rio Grande Marsh RNA.

Animals

The Refuge in general and Rio Grande Marsh in particular were established to protect wetlands for birds; the effort has been abundantly successful. Nearly all of the 295 bird species known on the Refuge (USDI—Fish and Wildlife Service 1982) might be found in the RNA, which provides a variety of habitats and even in "off" seasons is alive with wings. Nesting by waterfowl, shorebirds, and songbirds begins in April-May with the young hatching in May-June. Migrants from the north arrive in September-November, including large numbers of mallards, pintails, shovelers, teal, gadwalls, and ruddy ducks, snow and Canada geese, and greater sandhill cranes. Crane and waterfowl populations are near their peaks from late November through January. A few whooping cranes, the result of transplants, winter on the Refuge.

Frogs and toads, tiger salamanders, lizards, and snakes are common. Mammals include bats (14 species recorded in the Refuge), coyote, bobcat, raccoon, striped skunk, black-tailed jackrabbit, and cottontail. Of the many rodent species present, *Zapus hudsonius luteus* has been trapped in the research natural area.

Intrusions and Threats

The research natural area is surrounded by traveled roads and dikes. Fishing is allowed on the east side; however, no native-fish values are known here. Because of control projects along the Rio Grande, the area is no longer subject to inundation; water will be pumped into the lake and marsh to maintain near-constant levels. Pumping is expected to prevent entrance of rough fish (carp and bullhead), and the ponds will be allowed to dry out from time to time to eliminate those fish that do enter. Periodic burning is authorized for vegetation control, with a burn scheduled for the spring of 1983 to remove cattails. Non-native saltcedar has become a major component of the vegetation. Beehives are kept in the area, largely for saltcedar honey.

Research

Several University of New Mexico thesis studies in zoology have been done at the Refuge, and at least K. Peterson's on *Zapus* systematics (about 1980) involved Rio Grande Marsh. C. C. Reith studied bat activity, with results to be published in Southwestern Naturalist and Journal of Mammalogy. B. D. Woodward studied organization of anuran communities (1981).

Maps

Topographic: U.S. Geological Survey 1:24,000 series, Indian Well Wilderness Quadrangle, 1981. Soils: Poulsen and Fitzpatrick (1931), Maker et al. (1972). Geology: Bachman and Stotelmeyer (1967).

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SAN PASCUAL RESEARCH NATURAL AREA

Little San Pascual Mountain rises 700 feet above the west edge of the Jornada del Muerto on these varied 3,200 acres. Sedimentary and igneous rocks of Permian to Pleistocene ages are in evidence. Chihuahuan Desert grassland and shrubland, free and shrub-anchored dunes, and desert riparian vegetation form a mosaic. Pronghorn, mule deer, coyote, and golden eagle are among the many wildlife species.

Administration

Refuge Manager
Bosque del Apache National Wildlife Refuge
P.O. Box 1246
Socorro, NM 87801 (505) 835–1828

San Pascual is one of five natural areas in Bosque del Apache National Wildlife Refuge, administered by the Fish and Wildlife Service, U.S. Department of the Interior. The Refuge was established in 1939 on land purchased by the federal government in 1936 after many decades of grazing use. The approximately 3,200-acre (1,295-hectare) RNA was designated December 7, 1972. In 1975 the Congress made the area part of the 19,859-acre Little San Pascual Wilderness, from which vehicles are excluded.

The RNA is not posted as such, and is fenced only on the east side, which is the Refuge boundary. There is a locked gate across the roadway by the Little Black Mesas. The natural area is open in season for deer, quail, and rabbit hunting but not for pronghorn antelope. It has not been open to legal grazing for several years. Mineral entry, including prospecting, is prohibited.

Location and Access

San Pascual Research Natural Area is in Socorro County, centered at lat. 33°43′45″ N., long. 106°51′30″ W. (fig. 59). Were the area surveyed it would be in T. 6 S., R. 1 E., and, mostly, T. 7 S., R. 1 E. The east boundary is the Refuge boundary fence. The north boundary of the RNA is along the same roadway ("Pack Trail" of the 1982 topographic map) that is the south boundary of Jornada del Muerto Research Natural Area. The west boundary is 25 feet east of a pipeline that runs south-southwest from the sandstone buttes prominent on topographic maps. The south boundary is a problem: no remembered mapped features were used to delineate it, and we have been unable to obtain a definite location. Reputedly the boundary heads about west-northwest from a point near the north end of Section 17 next to the Refuge; thus Little San Pascual Mountain above 5,020 feet elevation would be in the RNA.

To reach the northeast corner of San Pascual RNA from Interstate 25, turn east on U.S. 380 10 miles south of Socorro. Starting from that exit pass San Antonio at 0.7 miles, the Rio Grande at 1.7, and turn south on Socorro County A153 at 7.4 miles; follow it past Fite Ranch at 9.3 to the Harriet Ranch junction at 20.3; thence continue west past a tank and well (Mike Well on 1982 map) at 22.7, where turn west-southwest off the bladed road on a sometimes-bumpy two-track and proceed to the Refuge fence and the RNA at 25.7 miles from I-25. At least for 4-wheel drive there are several points of access to the east side of the RNA and a trail along the Refuge boundary; to find them use no map older than 1982 topographic quadrangle. It is also possible to reach San Pascual RNA from Engel, which is on N.M. 52 40 miles to the south; carry water, maps, and in late summer, chains.

To reach the west side of San Pascual RNA from Refuge headquarters, during daylight only, go to Apache Camp RNA as described under that name; leave it on the left and go straight across the Main Conveyance Channel; turn north for a few yards till a road goes east over the high dike; follow that road to the natural channel of the Rio Grande. In fall and winter the channel may be dry enough to drive across; usually it can be waded. Roads lead south from this crossing for about 4 miles to the northwest corner of San Pascual RNA, just south of the conspicuous sandstone buttes (Little Black Mesas). Do not drive into designated wilderness, of which the western boundary here coincides with that of the RNA.

Accommodations are available in Socorro.

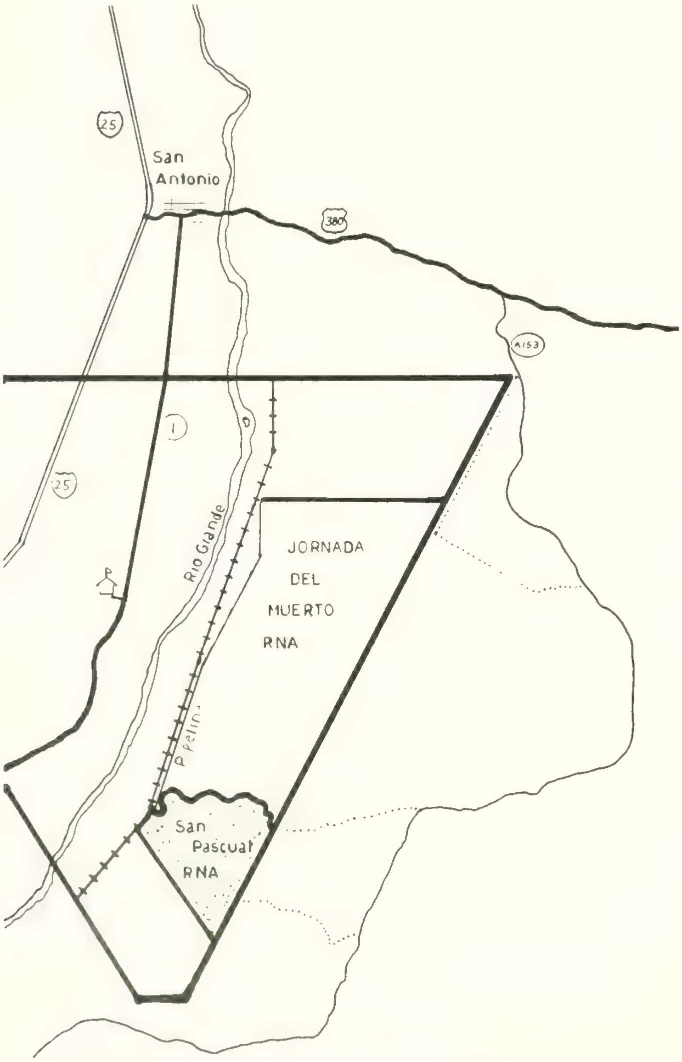

Figure 59. San Pascual RNA.

Climate

Climate is discussed by Houghton (in Maker et al., 1972): this is a warm, arid region with most of the 8 inches (200 mm.) of precipitation coming in late summer. Data from the weather station at Refuge headquarters, about 5.5 miles northwest, are in figure 7 under Apache Camp RNA, above.

Physiography, Geology, Soils

Little San Pascual Mountain, which occupies most of the RNA, is an isolated fault-block range typical of this Mexican Highland section of the Basin and Range Province (fig. 60). It rises 700 feet above the Jornada del Muerto Plain to the east (see Jornada del Muerto RNA in this report) and 1,000 feet above the floodplain of the Rio Grande, 1.5 miles west, to a height of 5,525 feet (1,684 m.). Lowest elevation in the RNA is 4,600 feet (1,402 m.) along the western edge, 0.6 miles west of the mountain front at 4,800 feet. That western part of the area comprises gentle ridges and sand-floored rocky washes, with one small group of free sand dunes. The mountain forms a divide between the Rio Grande drainage and the Jornada del Muerto closed basin.

Little San Pascual Mountain exposes Permian (Abo and Yeso Formations), Pennsylvanian, and Tertiary bedrock (Geddes 1963) (fig. 61). The Permian beds are a little outside the RNA to the south, as are the prospect pits and shaft that found a little copper in both Abo and Yeso Formations. Most of the mountain is gray to tan Pennsylvanian limestone, but also with arkosic sandstones and shales, partly silicified along the west margin of the mountain (Bachman and Stotelmeyer 1967). Identity of these Pennsylvanian rocks is discussed by Kottlowski (1960). Along the lower western slopes of the mountain are exposed, at the base, Paleocene andesite, and above it complexly bedded conglomerates, sandstones, and clay interbeds of the late Tertiary Santa Fe Group (in the wide sense). These are mostly poorly consolidated alluvium, but with some limy cement. The beds are mainly tan to yellowish gray; they dip gently west (Bachman and Stotelmeyer 1967).

Ascending from the valley bottom, the Rio Grande Entisol bottomland groups give way up the slope of the mountains to an Aridsol of Haplargids-Torripsamments construction. Except for the higher mountains the natural area is mapped for Berino-Bluepoint-Onite soils by Maker et al. (1972). This association is characteristic of the Jornada del Muerto in Socorro County. It includes several soil types, but mainly the three named, which have a thin surface layer of sandy loam or loamy sand over thick subsoils. These may be sandy clay loam (Berino), loamy sand or sand (Bluepoint), or sandy loam (Onite). Undulating or hummocky topography redominates in these deep soils in the RNA, with a few coppice dunes.

Maker et al. (1972) map Little San Pascual Mountain as bearing Rock Land-Lehmans-Lozier soils, characteristic of steep slopes with much exposed bedrock in Socorro County. These are thin soils with abundant loose rock; Lozier soil is strongly calcareous with limestone bedrock usually at 6 to 15 inches in depth.

Vegetation

Impressive diversity marks the plant communities. Black grama (*Bouteloua eriopoda*) covers part of the northeastern "flats," but other parts and also ridges and slopes throughout the RNA have creosotebush (*Larrea divaricata*) either as sole species or with *Muhlenbergia porteri*, prickly pears (*Opuntia* spp.), fluffgrass (*Erioneuron pulchellum*), three-awns (*Aristida* species), snakeweed (*Gutierrezia sarothrae*), fetid marigold (*Dyssodia acerosa*), and other species that often indicate degraded rangeland. Broom pea (*Psorothamnus* or *Dalea scoparia*) with sand sagebrush (*Artemisia filifolia*) and dropseeds (*Sporobolus* spp.) dominate the deeper, sandier soils. Mesquite (*Prosopis glandulosa*) is in some parts of the sand community (fig. 62). A tangle of shrubs takes over rocky areas in washes: sumac (*Rhus microphylla*), saltbush (*Atriplex canescens*), Apache plume (*Fallugia paradoxa*), sagebrush (*Artemisia* spp.), and a *Salvia*, with side-oats grama (*Bouteloua curtipendula*) and other relatively mesic grasses. The sumac occurs also atop dunes, and occasional saltbushes are scattered in creosotebush and other communities. Higher on the mountain are junipers (*Juniperus monosperma*) with saltbush and a variety of grasses. Almost pure stands of oreja de perro (*Tiquilia canescens*) occur on a few gravelly slopes. This species occurs also in limestone communities dominated by ocotillo (*Fouquieria splendens*), with creosotebush and dropseeds. Sumac (*Rhus aromatica* var. *trilobata*) and greasebush (*Forsellesia spinescens*) grow on the summit in crevices.

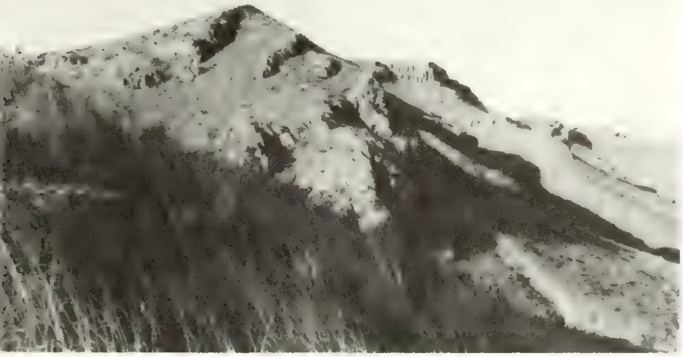

Figure 60. Little San Pascual Mountain from the northwest.

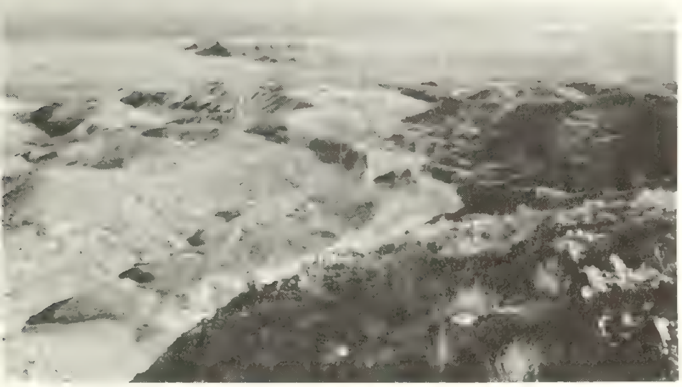

Figure 61. Northwest from Little San Pascual Mountain. The mid-ground Little Black Mesas are just outside San Pascual RNA.

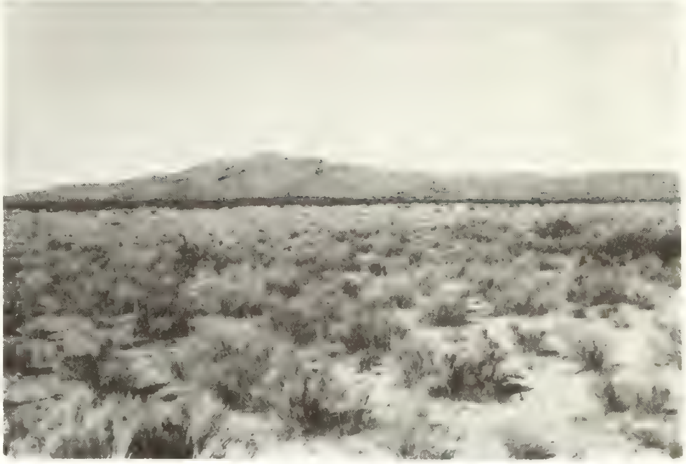

Figure 62. Sand sagebrush, dropseeds, a few mesquite bushes, and Little San Pascual Mountain and Center.

Near the northern edge of the RNA a sandy wash in a shallow box canyon supports a riparian community dominated by desert willow (*Chilopsis linearis*).

Küchler (1975) maps potential natural vegetation for this part of the Jornada del Muerto as Grama-Tobosa Shrubsteppe (his Type 58). This does apply to the northeast corner of the RNA. Most of the area might potentially bear the Mixed Dropseeds—Indian Ricegrass association of Donart et al. (1978), but with emphasis on its shrub components.

Animals

Findley et al. (1975) list 20 mammals including 11 rodent species collected in the vicinity that could occur in such a dry area as San Pascual; the nearest water is 1.5 miles east (a trough) or west (Rio Grande). Mule deer, black-tailed jackrabbit, desert cottontail, and coyote sign are common in the RNA, and pronghorns doubtless use the area. Quail, mourning dove, roadrunner, red-tailed hawk, and golden eagle were sighted in the summer of 1982. Several snake and lizard species are common.

Intrusions and Threats

The north boundary road has been patrolled 2 or 3 times a year in recent years; no other vehicles are allowed. The west boundary is an incompletely buried pipeline accompanied by a faint two-track road and a few route markers. The east boundary—the Refuge fence—is accompanied on the outside by a jeep trail. A road entered the southeast corner of the RNA at boundary marker 23 and led to a structure 400 yards within the area, but 1972 aerial photos do not show these old intrusions.

In general the area seems isolated and remarkably free of man's works except for rather large numbers of his cattle outside the eastern boundary fence.

Research

Only geological field work is known.

Maps

Topographic: USDI—Geological Survey 1:24,000 series, Little San Pascual Mountain Quadrangle, 1982; and the western-most 120 acres are on the San Marcial Quadrangle, 1982. Soils: Maker et al. (1972). Geology: Geddes (1963).

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VEGOSA RESEARCH NATURAL AREA

Grassland and juniper-oak savanna cover this gently sloping, 537-acre wildlife (and livestock) area. Potentially a fine example of plant and animal life of the Las Vegas Plateau, the land has not fully recovered from past overgrazing.

Administration

Refuge Manager
Las Vegas National Wildlife Refuge
P.O. Box 1070
Las Vegas, NM 87701 (505) 425–3581

The 9,450-acre Refuge is a unit of the National Wildlife Refuge System administered by the Fish and Wildlife Service, U.S. Department of the Interior. The Refuge was established on purchased land in 1966 to restore an area that had been an important wildfowl resting area in years past. The 537-acre (217-hectare) research natural area, designated August 17, 1973, contains no permanent water so is not directly involved with waterfowl.

Cattle are grazed in the RNA under permit to local ranchers. The northeast section of Vegosa was grazed in September of 1980 and in August of 1982, but rested in 1981. The southwest section was grazed for 5 weeks in September-October 1981 but rested in 1980 and 1982.

The RNA is not posted nor fenced as such, though along the south and east borders occasional signs mark the Refuge border and forbid unauthorized entry. A permit from the Refuge Manager is required to visit the RNA. Hunting is prohibited there.

Location and Access

Vegosa Research Natural Area is in San Miguel County at lat. 35°30′40″ N., long. 105°09′15″ W., (fig. 63). Part of the Las Vegas Grant, the area was not included in the United States land survey, but would be in T. 15 N., R. 17 E. The boundaries are irregular and defined mainly by topography: the RNA is in the southeast corner of the Las Vegas National Wildlife Refuge and includes the plateau within about 2,000 feet of the lip of Vegosa Canyon, with a western limit along long. 105°10′07″ W., and a northern limit along lat. 35°31′17″ N.

Las Vegas National Wildlife Refuge is 5 miles southeast of Las Vegas. From downtown Las Vegas or from the N.M. 65–104 exit of Interstate 25, drive east on N.M. 65–104 about 1.5 miles, turn south on N.M. 281 and follow its turns for 4.5 miles to Refuge headquarters, where a permit to enter the RNA may be sought. Vegosa RNA is at the southeastern extremity of the Refuge, 3 miles south of headquarters or a mile southeast of McAllister Lake. Unless gates that are ordinarily locked are opened, the last 0.75 miles must be covered on foot.

Accommodations are in Las Vegas. Camping is permitted at McAllister Lake, in an area managed by the New Mexico Department of Game and Fish.

Climate

This is a cool, moist area with mean temperature 50°F (10°C) and average annual precipitation of 16 inches (400 mm.). Climate of the area is discussed by Griggs and Hendrickson (1951) and by Hilley et al. (1981). Monthly data at Las Vegas are given in figure 22 under Gallinas RNA, which is almost adjacent to Vegosa RNA.

Physiography, Geology, Soils

The Refuge is at the southwestern edge of the Las Vegas Plateau and the western edge of the Great Plains. This corner of the Plateau is in the Pecos River drainage.

Typical of the Plateau, Vegosa RNA is a peneplain deeply cut at its edge by a steep-sided river canyon. The long eastern border of the RNA is the lip of Arroyo Vegosa (Vegosa Creek Canyon), which joins the Gallinas River a few hundred yards south of the RNA. The canyon is 300 feet deep and averages about 1,200 feet wide at the top: the average slope of its sides is 45%. The creek (outside and below the RNA) is small but apparently permanent. The uppermost 12–20 feet of canyon walls are vertical cliffs, but there are occasional breaks that can be clambered over.

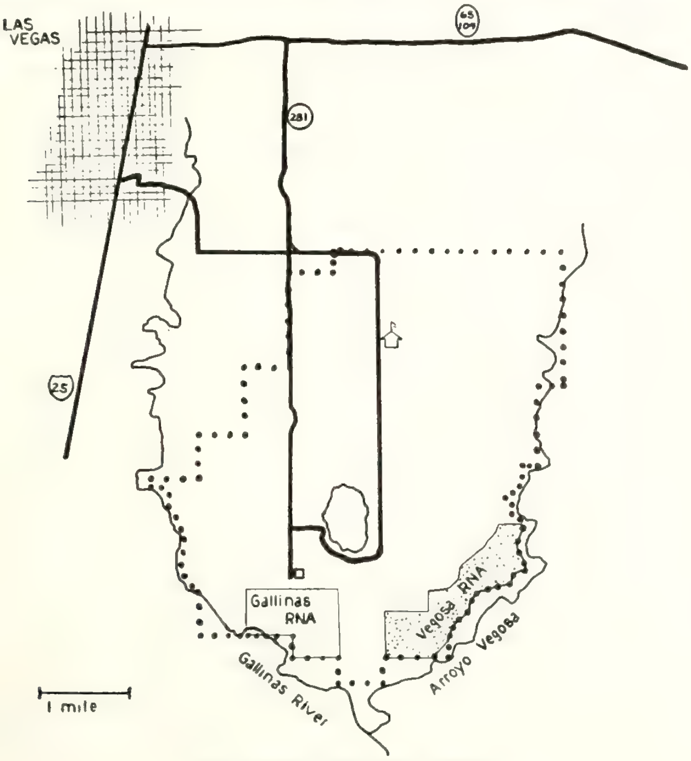

Figure 63. Vegosa RNA.

Except near its southwest corner, the RNA slopes gently away from the edge of the canyon, so that drainage is northwestward, mostly to McAllister Lake, which has no surface outlet. Except in the southwest corner the elevation drop is from 6,540 to 6,500 feet (1,993–1,981 m.) or less across the 0.4-mile-wide area. The southwest corner drains southward through a steep side canyon of the Vegosa, which leaves the RNA at 6,380 feet (1,945 m.) elevation. This side canyon is normally dry but, just as along the lip of the canyon, there are small, shallow pools in rocky basins after rains.

Bedrock is the Dakota Sandstone, of Late Cretaceous age, which serves as a caprock here and over much of the Las Vegas Plateau. It is exposed along the escarpment. Griggs and Hendrickson (1951) describe the formation as fine-grained, highly quartzitic sandstone, containing pebbles of quartz and of chalcedonic silica. Exposures in Vegosa RNA have all weathered to brown or reddish-brown. At Las Vegas the Dakota's thickness is 220 feet. Jacka and Brand (1972) and Lessard and Bejnar (1976) give further geologic data.

Soils are mollisols of the great group Argiustolls, except for the Tricon component, a Petrocalcic Paleustoll (Hilley et al. 1981). On a 500-foot-wide strip along the escarpment and in the western edge of the RNA is the shallow, well-drained Bernal loam, lying on sandstone less than 2 feet down. Most of the rest of the RNA comprises Partri-Carnero Association, a mix typically of 55% Partri silt loam and 30% Tricon silt loam, with small areas of Bernal and Carnero soils. This association is deep and well-drained. Four areas along the northwestern border have Carnero loam, also deep and well-drained.

Vegetation

This is grassland, but along the escarpment there is a strip (corresponding with the distribution of thin, Bernal soil) of open woodland composed of junipers (*Juniperus monosperma* and *J. scopulorum*), pinyon (*Pinus edulis*), and wavyleaf oak (*Quercus undulata*) (fig. 64). Down-slope (northwest) of the woodland are widely spaced one-seed junipers, mostly young, indicating invasion of the grassland. Parts of the edge of the canyon support a thin line of ponderosa pine, and young ponderosas, along with Rocky Mountain junipers, are prospering in the southwestern side canyon. Associated with the conifers are many grasses, among them *Muhlenbergia montana, Panicum bulbosum, Eragrostis intermedia, Agrostis scabra, Schizochyrium scoparium, Sorghastrum nutans, Lycurus phleoides, Andropogon gerardii*, and, commonest of all on the side-canyon rocks, *Blepharoneuron tricholepis* (fig. 65).

The open grassland is a patchy mixture of many species, but with a preponderance of species such as three-awns (*Aristida* spp.), squirreltail (*Sitanion hystrix*), hairy tridens (*Erioneuron pilosum*), blue grama (*Bouteloua gracilis*), ring muhly (*Muhlenbergia torreyi*), and sage (*Artemisia carruthii*) that indicate past overgrazing. Better grass stands occur in parts of the juniper savanna, for instance extensive wolftail (*Lycurus phleoides*) and patches of needle-and-thread (*Stipa comata*) and of sideoats grama (*Bouteloua curtipendula*).

The grassland is a meeting place of southern, Rocky Mountain, and Great Plains species, for instance *Eragrostis curtipedicellata* at its western limit.

Northern spleenwort (*Asplenium septentrionale*) is common in crevices in the cliff at the top of the escarpment.

Although Vegosa RNA has been listed as potentially producing Grama-Buffalo Grass (Küchler's Type 65), that type seems here to be limited to Carnero soils, which are scarce in the RNA. Classification as Grama-Galleta Steppe (Küchler's Type 53) seems more realistic.

Animals

Mule deer, Nuttall's cottontail, coyote, and bobcat are common. A large number of rodent species seems probable, but no list for the Refuge is available. Other likely mammals are desert shrew, gray fox, raccoon, long-tailed weasel, mink, striped skunk, mountain lion, and black-tailed jackrabbit.

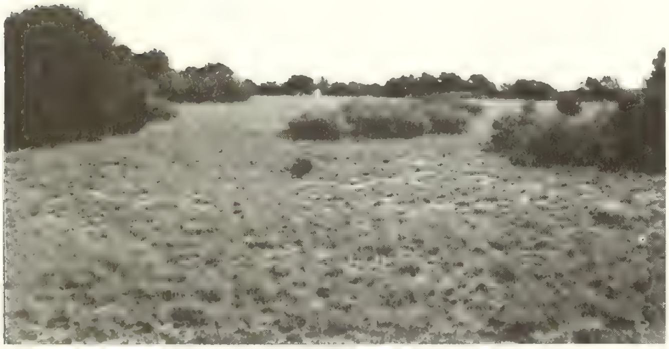

Figure 64. Oak-juniper savanna. Vegosa RNA.

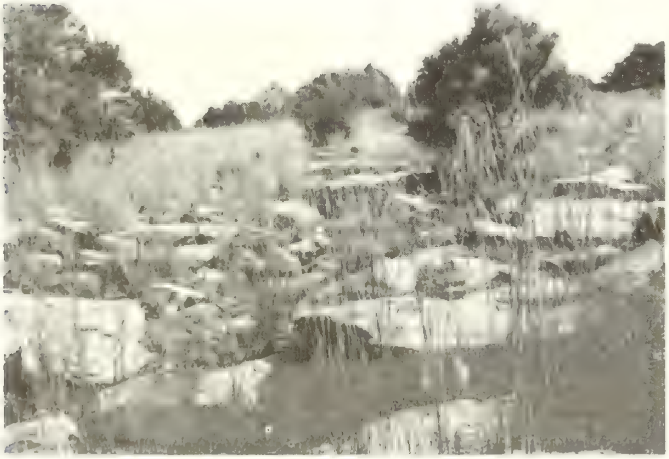

Figure 65. Tall grasses, pinyon and ponderosa pine in a side canyon. Vegosa RNA.

Turkey, prairie falcon, and red-tailed hawk are conspicuous. Burrowing owl, long-billed curlew, scaled quail, roadrunner, golden eagle, and (in winter) bald eagle have been cited for the area. The Refuge bird list (USDI—Fish and Wildlife Serv. 1972) includes 131 species other than waterfowl, 54 of them known to nest in the Refuge.

Intrusions and Threats

A 2-track road through the RNA parallels the escarpment; it is still in use for Refuge vehicles. At the eastern end of the area the road goes out on a narrow "peninsula" to the canyon rim. Pre-Refuge domestic trash dumps, no longer conspicuous, are near the east and southwest extremities of the RNA. There are shallow caliche or gravel pits, with accompanying mounds, just inside and just outside the RNA's western border. The RNA, though not fenced on its perimeter, is cut by a fence (newer than RNA status?) that separates the northernmost third of the area from the rest.

Livestock grazing, discussed above under "Administration," is probably the major non-natural intrusion; it is intended to maintain the shortgrass community.

Research

None is known.

Maps

Topographic: U.S. Geological Survey 1:24,000 series, Las Vegas Quadrangle, 1963. "Arroyo Pagosa" of this map is called "Arroyo Vegosa" in the present report, it being thought locally that "Pagosa" was wrong. Geology: Griggs and Hendrickson (1951). Soils: Hilley et al. (1981). Aerial photography: Hilley et al. (1981).

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Peterson, Roger S.; Rasmussen, Eric. 1985. Research Natural Areas in New Mexico. USDA Forest Service General Technical Report RM–136, 58 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

New Mexico's 17 Research Natural Areas are described. Included are maps, photographs, and brief accounts of administration, climate, physiography, geology, soils, vegetation, fauna, research uses, and references. Threats and intrusions are noted.

This information should be useful to scientists interested in conducting botanical or zoological research in New Mexico.

Keywords: Research Natural Areas, New Mexico

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

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Department of
Agriculture

Forest Service

Rocky Mountain
Forest and Range
Experiment Station

Fort Collins,
Colorado 80526

General Technical
Report RM-137

Proceedings: Combined Western Forest Nursery Council and Intermountain Nursery Association Meeting

August 12-15, 1986
Tumwater, Washington

Landis, Thomas D. Proceedings: Combined Western Forest Nursery Council and Intermountain Nursery Association Meeting; 1986 August 12-15; Tumwater, WA. Gen. Tech. Rep. RM-137. Fort Collins, CO: U.S Department Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1986. 164 p.

Abstract

This proceedings is a compilation of over 30 technical articles on various phases of container and bareroot nursery management. Specific areas addressed include: seed production, cultural practices, seedling quality, nursery pests, seedling storage, and computers.

Keywords: Tree nurseries, greenhouses, tree seedlings, containerized seedlings.

USDA Forest Service
General Technical Report RM-137

December, 1986

Proceedings: Combined Western Forest Nursery Council and Intermountain Nursery Association Meeting

August 12-15, 1986
Tumwater, Washington

Technical Coordinator:

Thomas D. Landis
Western Nursery Specialist
Rocky Mountain Region
USDA Forest Service

Rocky Mountain Forest and Range
Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado

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Pesticide Precautionary Statement

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers—out of reach of children and pets—and away from foodstuff.

Apply pesticides selectively and carefully. Do not apply a pesticide when there is danger of drift to other areas. Avoid prolonged inhalation of a pesticide spray or dust. When applying a pesticide, it is advisable that you be fully clothed.

After handling a pesticide, do not eat, drink, or smoke until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If the pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

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PROTECT

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Where Are We Headed, and What Should We Be Planning For?[1]

John P. McMahon [2]

INTRODUCTION

Good morning.

I want to thank you for the opportunity to be with you this morning.

As nurserymen, you play a crucial role in the reforestation process, which is essential to the future of forest management in the Northwest. I believe it is very appropriate that we get together periodically to share ideas and discuss mutual problems and opportunities. It is encouraging to see so many interested professionals from both the public and private sector involved in this forum.

THEME

I would like to propose the following theme for my remarks this morning, as well as for the balance of this four-day session. That theme is:

"Where are we headed and what should we be planning for?"

Before discussing where we are going, it is well to recognize where we are now and how we got here.

We have indeed come a long way from the low levels of forestry characteristic of the mid 60's, when direct aerial seeding was the primary means of man-influenced reforestation west of the Cascades. Public and private foresters alike recognized the need for more reliable regeneration methods, and the implications for future growth and yield, if rapid regeneration with controlled spacing could be assured following logging. At the same time, during the 1970's, regeneration requirements resulting from strengthened state forest practices acts and new federal laws increased the demand for planting stock for private, state and federal lands. Nursery capacity expanded through the early and mid-70's to meet this increased demand for seedlings. Private industrial landowners increased their efforts to rehabilitate poorly stocked acres and convert hardwood stands on high sites back to conifer production. The U.S. Forest Service received an extra "one-time" mandate to eliminate a sizable reforestation backlog, with the National Forest Management Act of 1976. By 1985, this resulted in more than one million acres actually treated nationwide...nearly three quarters of which occurred on the western National Forests.

The decade of the '70's was also a period of rapid change in the development of successful stock types and growing regimes. This was, and continues to be, a dynamic process. Some technology was borrowed from other parts of the world, but much local knowledge and experience had to be gained. Research has played an important role in developing that knowledge. Initially most nursery research was sponsored by larger organizations. I think it is significant that an active nursery cooperative research effort has become established here in the Northwest in the early 80's, allowing access to research results by independent nurserymen as well as private non-industrial forest landowners.

Since the early days of nursery management, we have gained a much better understanding of physiological processes as they relate to seedling performance. Research on culture, lifting, and storage has had perhaps the most significant influence on improvement in quality, and we have become much more sophisticated in how we measure seedling quality. Container systems rapidly emerged as an expected solution to bare-root problems, particularly in the higher elevations, in the mid 70's; then declined somewhat as we learned to culture for better root development, as well manage bareroot dormancy through timing of lifting and duration of storage. Although diminishing somewhat in volume, plug seedlings continue to be a very valuable special purpose stock type and are still regarded by many as a general purpose stock type. Clearly, the demand is still there for both types of seedling production systems.

---

[1] Paper presented at the meeting of the Western Forest Nursery Council, Olympia, Washington, August 12, 1986.

[2] John P. McMahon is Vice-President, Timberlands, Weyerhaeuser Company, Tacoma, Washington.

Although we are consistently growing a higher quality product than ten or fifteen years ago, we still have some important opportunities ahead of us.

WHAT ARE THOSE OPPORTUNITIES AND WHAT SHOULD WE BE PLANNING FOR?

In assessing our future, we need to look at essentially two areas:

- One is the changing nature of our **markets**.
- The other is the set of **technical issues** we must deal with in order to meet the seedling performance expectations of the forest manager.

If we look at harvest levels in the Douglas-fir region for the next decade, private industrial harvest will trend downward to about 80 percent of today's level. Offsetting increases in non-industrial private harvest, are expected to maintain total private harvest near their mid-1980 levels. Although there are some uncertainties regarding the new National Forest Plans, it appears that there will be a reduction in Region Six harvest levels of between 10 and 20 percent from recent levels by 1990. This will have definite implications for regeneration requirements on the National Forests. In addition, the NFMA mandate to eliminate the regeneration backlog on Forest Service lands is now fulfilled. Harvest levels and regeneration requirements on state lands in Washington and Oregon will remain essentially as they are today.

Stocking levels on public and private lands have been reduced considerably over the past five years, as survival has improved and better data on the effects of stocking on long term growth and yield have become available, and we expect this trend to continue. Where we formerly planted 650 or more trees per acre, 350-500 trees per acre has become more common. That represents a very significant reduction in seedling requirements across the number of acres being planted.

In addition to changes in seedling demand, we can predict that such things as species mix and stock type mix will change as geographic distribution of planting changes, as well as customer perceptions of stock type performance.

These trends indicate a static or perhaps reduced demand for seedlings in the west for the next few years. Consequently, we should now view our challenges to be more in the technical area, as opposed to further expansion of seedling production operations. These would include such things as:

1. Servicing each customer's special needs - "fine tune" his seedlings for more site-specific requirements.
2. Maximizing seedling yield from the increasing amounts of higher value seed becoming available from tree improvement programs.
3. Adapting growing systems to accommodate the emerging technologies of tissue culture and clonal propagation.
4. More fully exploiting existing research knowledge in day-to-day operations - accomplish technology transfer effectively.
5. And, of course, controlling costs and maintaining yields, which are key to the success of any operation, must never be taken for granted. These require continual effort.

R&D NEEDS/OUTLOOK

Research will continue to play an important role in meeting these challenges. I would broadly summarize our research needs as follows:

1. Continued emphasis on identifying cost-effective alternatives in nursery weed control.
2. Continued work in seedling pathology - specifically in dealing with Fusarium, Pythium, Phytophera and Phoma.
3. Nursery cultural techniques to reduce the need for more expensive transplants on some sites.
4. Quality sowing - to enhance seedling yield and maximize utilization of valuable seed.
5. Increased volumes of genetically improved seed will place some unique demands on our current system in the near future:
   a. The ability to plant more acres with improved stock earlier to capitalize on gain per unit of time will demand maximum utilization of seed.
   b. The ability to multiply the **best** of this material through vegetative propagation will provide a strong economic incentive to modify and adapt cultural practices to successfully produce rooted cuttings in Douglas-fir.

There may also be some compelling reasons to propagate clonal material with special characteristics such as:

- rust-resistant white pine
- Christmas tree genotypes with desired traits
- families that have demonstrated superior performance on specific sites (GXE interaction)
- ability to propogate trees with special traits, such as high specific gravity for increased fiber yield

"THE JOB DOESN'T STOP AT THE LOADING DOCK"

I would like to leave you with one additional thought that we at Weyerhaeuser Company consider to be very important: That is, **"the job doesn't stop at the loading dock."**

The customer has become more **sophisticated** and **demanding.**

. **Sophisticated:** In terms of understanding variables that affect plantation performance.

. **Demanding**: In terms of seedling attributes that meet their needs in a cost-effective manner.

As in any other type of marketing, it is essential that we work closely with and understand the needs of the end user if we are to fulfill our mission as nurserymen. In my own experience at Weyerhaeuser Company, I regard this close link with the field forester as one of the key factors in continual improvement in seedling quality. The results are evident in terms of significantly improved survival and growth over ten years ago. I'm sure many of you could relate similar experiences.

CLOSING REMARKS/SUMMARY

In closing, I would like to emphasize that your contributions as nurserymen are key to the future of western forest productivity. Through application of your skills and dedication to the task of producing quality seedlings, coupled with the increasingly important contribution of the western tree improvement programs, and the tools of the silviculturist, we can expect the future forest resource in the west to become increasingly productive on those acres that are intensively managed for timber production. In so doing, we can offset the inevitable loss of parts of the commercial forest land base to wilderness, NFMA restrictions, and urbanization, and thereby fulfill society's increasing demand for the full range of forest resources.

Thank you.

Western Larch Cones and Seeds--Current Intermountain Research Station Studies[1]

Raymond C. Shearer[2]

Abstract.--In 1985, two studies involving western larch cone and seed production were begun. The first determines the influence of spacing on seed cone production of 30- to 32-year-old larch in western Montana. The second identifies factors limiting western larch cone production in forest stands of Idaho and Montana.

INTRODUCTION

The Intermountain Research Station's Silviculture Research Work Unit located in Bozeman and Missoula, Mont., began four western larch *(Larix occidentalis)* cone and seed studies during the past 20 years. Two have been completed, two are underway. A brief review of results of two completed studies appear here; details are available in three publications cited. The remainder of this paper reports preliminary results of the two new, ongoing studies.

COMPLETED STUDIES

From 1964 through 1967, we studied the reliability of several factors for predicting western larch seed maturity on five larch growing at 4,000 feet on a north aspect near Missoula, Mont. (Shearer 1977). This study also determined if the period of cone collection (usually from late August through mid-September) could be extended. Embryo development (ratio of embryo length to seed cavity length) was complete in seeds from three study trees by early August and for two others by mid-August 1964. Specific gravity (about 0.75) and moisture content (about 25 percent) accurately predicted when cones would open. Although both indices decreased with advancing cone maturity, they did not give a clear indication of when cones were sufficiently mature to pick. Color is a poor indicator of cone maturity because of the wide range in cone colors within and among individual trees as cones mature. The study showed that cones on an individual tree open within a week, but cone opening among the trees varied considerably. Nearly all sound larch seed germinated when cone collection began by mid-August and cones were stored in well-ventilated areas for several weeks before seed extraction.

A second study began in 1980 at four locations in western Montana to determine the extent of damage to larch cones by western spruce budworm *(Choristoneura occidentalis)* and other insects. Shearer (1984) reported 3-year results. In 1980 and 1982, about two-thirds of the larch seeds were killed by insects. Cone production failed in 1981 because few, if any, ovulate buds formed in 1980. Second- and third-stage budworm larvae killed the small, developing larch cones soon after the ovulate buds opened. Occasionally, the budworm larvae ate seeds while randomly feeding within the developing larch cones, as described earlier by Fellin and Shearer (1968). A woolly aphid and a cone maggot caused heavy losses of cones and some loss of seed (Shearer 1984). A seed chalcid and a seedbug also killed a very few seed. Only 19 and 8 percent of the seeds were filled in 1980 and 1982. Empty and aborted seed made up 45 and 16 percent of the larch seed in 1980 and 1982. Larvae fed on filled, hollow, and aborted seed of mature cones, so the actual number of each were unknown.

---

[1] Paper presented at the Western Forest Nursery Council Meeting. [Vance Tyee Hotel, Tumwater, Wash., August 12-15, 1986.]

[2] Raymond C. Shearer is Principal Silviculturist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture; Forestry Sciences Laboratory, Missoula, Mont.

The second study also determined the number of cones that matured on larch trees within each of the four study areas from 1980 through 1983 (Shearer 1986). A good cone crop in 1980 accounted for 80 percent of all cones counted during the 4-year study. In 1980, cones matured on 85 percent of the larch in the 12- to 14-inch diameter class but only 38 percent matured on trees in the 4- to 6-inch diameter class. Cone production also was influenced by tree size. The average number of cones per tree in 1980 increased 27 times as the diameter classes increased from 4 to 6 inches to 12 to 14 inches. In years of fair or poor cone production the average number of cones per tree was about 15 times greater in the 12- to 14-inch diameter class than in the 4- to 6-inch diameter class. More than half of the larch in the 4- to 6-inch diameter class failed to mature any cones during the study; only 7 percent of the trees in the 12- to 14-inch diameter class failed to mature cones during the same period.

ONGOING STUDIES

In 1985, two additional studies began on western larch cone and seed production:

Study 1

Young, managed stands of western larch are gradually replacing the virgin forests that have dominated the Northern Rockies. Because of the importance of knowing the cone producing capabilities of young larch, this study, Cone Production on Immature Larch as Influenced by Spacing in Western Montana, is designed to identify the effects of stand density (spacing) on the frequency and amount of seed cone production. Initial results (spring 1985) are reported by Shearer and Schmidt (in press) and summarized in this paper.

Study 2

Western larch has produced few mature cones for many years within much of the panhandle of Idaho and in some nearby Montana stands, even when excellent cone crops occurred elsewhere in western Montana. Reasons for the lack of cone production are unknown. This study, Larch Cone and Seed Potential in Northern Idaho and Western Montana--Magnitude and Causes of Cone and Seed Failure, will identify the major factors reducing larch cone and seed potential in northern Idaho and in adjacent western Montana. Early results (1985 through early July 1986) are summarized here from a paper by Shearer and Theroux (in press).

STUDY AREAS AND METHODS

Only brief descriptions of study areas and types of data collected are presented. In-depth descriptions are contained in the study plans; short descriptions are given in the "in press" publications cited.

Study 1

Study 1 was superimposed on long-term research plots designed to evaluate the effects of spacing on the growth of young western larch. Four sets of plots were established in western Montana: two at Coram Experimental Forest near Glacier National Park; one at Cottonwood Lakes near Seeley Lake, about 93 miles south of Coram; and one at Pinkham Creek near Eureka, about 93 miles northwest of Coram. Elevations at the Coram plots averaged 3,820 feet, at Cottonwood 5,300 feet, and at Pinkham 4,870 feet. Site indices at 50 years were about 59 at Coram, 52 at Cottonwood, and 69 at Pinkham. In 1985, the average heights and ages of the sample trees were:

Coram 1 - 46 feet, 32 years
Coram 2 - 43 feet, 32 years
Cottonwood - 30 feet, 30 years
Pinkham - 43 feet, 30 years

Four densities were selected to study cone production at all four locations. An additional two densities were selected at the two Coram locations, resulting in 20 plots used to measure cone production. Densities and spacings were:

Locations	Densities Trees per acre	Average spacing (*feet*)
Coram 1 and 2 only (unthinned plots)	∿15,000	∿2.0
All locations	1,740	6.5
All locations	680	8.0
All locations	360	11.0
All locations	200	15.0
Coram 1 and 2 only	110	20.0

Cone production is being monitored on the 10 tallest trees per plot. Binocular counts of cones in May and late August each year are made from one point for each tree.

Study 2

Study 2 identifies (1) frequency and amount of potential cone production, (2) cone development, and (3) factors reducing cones and seeds. Nine study areas were selected in northern Idaho, ranging from near New Meadows in the south to near Bonners Ferry in the north. Two sites were chosen in western Montana, one near St. Regis and the other close to Libby. All areas are within larch forests originating after wildfires earlier this century. At each study area, 10 open-growing dominant larch were selected that met three selection criteria: (1) crown length at least 40 percent of the total tree height, (2) accessible for climbing, and (3) evidence of prior cone production. Potential cone production and actual number of mature cones were determined on the five sample trees that were judged (from binocular counts) to have the greatest cone potential. Cone development and condition were determined at each visit for cones marked on two trees of each study area. Factors reducing cone and seed production were identified at each visit to the study areas by examining the marked cones and other evidence found in the trees. Unmarked cones were collected at each visit and dissected later to determine damage to cones and seeds.

RESULTS

The results shown here are preliminary because they represent only 1 or 2 years' data from each 5-year study.

Study 1

Although seed cone production in young western larch began several years ago, most trees had relatively few if any developing cones at the time of the first measurement in May 1985. The maximum was 65 on a tree in the 15-foot average spacing.

All seed cones were produced on ascending branches or on the 1981 to 1984 terminal leaders, except within the 20-foot average spacing plots at Coram. There, half the trees produced cones on both ascending and horizontal branches. Most seed cones at all locations were produced within the upper third of the crown. Of the trees with cones, 76 percent had cones only in the upper third of the crown, 19 percent had cones in the upper two-thirds of the crown, and 5 percent produced cones only in the central third of the crown.

In 1985, more trees produced cones at both of the moderately productive sites at Coram and at the more productive site at Pinkham than at the less productive Cottonwood site (table 1). About 19 percent of all sample trees produced cones in 1985, ranging from 0 and 2.5 percent in the unthinned and 6.5-foot spacing plots to 30 and 50 percent in the 15- and 20-foot spacing plots. These early results show that trees designated for seed production must be open grown and full crowned to produce large numbers of cones.

Table 1.--Percent of trees in May 1985 that had new developing seed cones by location and average spacing. Sample size: 10 trees per location and spacing. Adapted from Shearer and Schmidt (in press)

	Spacing (feet)					
Location	20	15	11	8	6.5	Unthinned
Coram 1	40	60	10	10	0	0
Coram 2	60	0	30	30	0	0
Cottonwood	[1]--	20	10	0	0	[1]--
Pinkham	[1]--	40	20	30	10	[1]--

[1] No plot established.

Wider spacing of trees produced more seed cones (table 2). No cones were found on any of the unthinned-plot trees. Only one of the 40 sample trees in the 6.5-foot spacing produced cones--it had 18--for an average of 0.4 per sample tree. The number of developing

Table 2.--Average number and standard deviation (±) of new developing seed cones per tree in May 1985 by location and average spacing. Sample size: 10 trees per location and spacing. Adapted from Shearer and Schmidt (in press)

	Spacing (feet)					
Location	20	15	11	8	6.5	Unthinned
Coram 1	6± 9	10±21	2± 8	1±2	0	0
Coram 2	13±18	0	6±10	4±8	0	0
Cottonwood	[1]-----	<1± 1	1± 4	0	0	[1]--
Pinkham	[1]-----	8±17	<1± 1	1±2	2±6	[1]--
Average	[2]10±14	5±14	2± 6	1±6	<1±3	[2]0

[1] No plot established.
[2] Coram average only.

seed cones per tree averaged 9.5 in the 20-foot spacing, 23 times greater than in the 6.5-foot spacing.

Study 2

In 1985 and 1986, cones potential (developing cones) occurred at all study sites and on nearly all study trees. There was a broad range in cone potential among these trees, both within and among stands (table 3). The four study areas with the greatest cone potential in 1985 also had the best potential in 1986.

Buds of larch seed cones open much before those of other conifer species, often when snow still covers the ground. In 1985 and 1986, seed cone buds opened in late March to early April within the four study areas between 2,500 and 3,900 feet elevation. The ovulate buds probably opened by mid-April at the five sites between 4,500 and 4,800 feet elevation, and by late April at the two study areas at 5,000 and 5,800 feet elevation. Approximate dates for bud opening are given because snow blocks most of the roads, preventing early access to the study sites.

Cone elongation quickly followed bud opening and was complete or nearly complete by early July. Cone maturity occurred in August after the embryos were fully developed within the seeds, as described previously by Shearer (1977).

Insects and frost killed nearly all potential cones in 1985 and 1986. Even the few cones that matured usually contained seeds that were damaged by insects. As a result, almost no viable larch seed was dispersed on our study areas in northern Idaho in 1985 and even fewer are expected in 1986.

After the ovulate buds opened, frost killed all or most of the developing seed cones at all but the lower elevation sites. Although we are unsure of the threshold temperature that freezes and kills young cones, temperatures as low as 25 °F in 1986 did not kill or visibly damage the young cones at the low-elevation Twin study area. All other sites, where frost was a problem, had lower minimum temperatures (as low as 17 °F).

Periodic cone collections from areas with surviving cones showed that insect damage began by late April. In 1985, a woolly aphid (probably a species of *Adelges*) was found on cones at Meadow, Standard, and Twin, but not at Twelve Mile or Beacon. None were found in 1986. In 1985 and in 1986, one or more cone maggot larvae (probably a species of *Hylema*) fed within many cones that survived the frost. An unidentified scale midge was found on many cones in late June, 1985.

In 1985, frost killed all cones at four of nine study areas, killed from 40 to 71 percent of the cones at three other sites, and caused no losses at the two lowest elevation sites (table 4). All of the cones at Twin were killed by insects, about 90 percent by woolly aphid, and 10 percent by cone maggot larvae. In 1986, no woolly aphids were observed on the developing cones. At Meadow in 1985, 44 and 47 percent of the cones were killed by woolly aphids and cone maggots,

Table 3.--Average number of cones per tree estimated soon after bud opening in 1985 and 1986 on 11 study areas. From Shearer and Theroux (in press)

	1985				1986			
Study area	Cones	Sx	Range	n	Cones	Sx	Range	n
	(No.)				(No.)			
Meadow	1,220	354	416-2,288	5	2,879	905	892-6,137	5
Standard	199	70	1- 432	5	24	9	3- 58	5
Twin	656	197	304-1,232	5	56	28	9- 160	5
Twelve Mile	267	110	42- 563	5	287	168	76- 957	5
Beacon	828	113	471-1,082	5	1,354	400	36-4,039	10
Cairn	[1]--				322	122	2- 688	10
Brushy Fork	[1]--				284	164	0-1,722	10
Savage	163	143	0- 736	5	111	100	0- 512	5
Ericson	981	351	121-1,937	5	1,527	343	553-2,383	5
Peter	1,270	494	366-2,795	5	1,181	357	178-2,275	5
Brush Mountain	318	180	75-1,029	5	485	228	81-1,316	5

[1] Not established, no data collected.

Table 4.--Percent cone survival and mortality by cause. From Shearer and Theroux (in press)

	1985			1986		
		Mortality			Mortality	
Location	Survival	Frost	Insects	Survival	Frost	Insects
Meadow	12	0	88	0	100	0
Standard	2	40	58	0	[1]100	0
Twin	0	0	100	[2]--	0	[2]--
Twelve Mile	10	63	27	0	100	0
Beacon	16	71	13	0	100	0
Other[3]	0	100	0	0	100	0

[1] Two nonplot trees had a few cones that survived the frost.

[2] Data not complete on July 7, 1986.

[3] Savage, Ericson, Peter, and Brush Mountain in 1985 and 1986; Cairn and Brushy Fork 1986 only.

the remaining 9 percent by unidentified insects. At the other three locations, the cone maggot caused most of the insect-caused mortality.

Frost killed all cones on 10 of the 11 sites in 1986, although a few cones survived on two trees at Standard (not on the study plots) (table 4). For the second year no cones were killed by frost at Twin. No insect data are available at this time.

Less than 10 percent of the seed extracted from cones collected at four sites in 1985 were sound (table 5). The average number of sound (potentially viable) seed per tree ranged from about 32 at Standard to 1,466 per tree at Meadow. Insects damaged 26 to 55 percent of the potential seed at the four locations. Empty and abnormal (often aborted) seeds made up 38 to 65 percent of the potential seed on these areas.

Table 5.--Estimated number of seeds produced per tree at four study areas in 1985 and the percent of filled, damaged, and other nonviable seed. From Shearer and Theroux (in press)

Location	Estimated seeds per tree	Filled	Insect damaged	Other nonviable
	(No.)	- - - -	-*Percent*-	- - - -
Meadow	20,950	7	55	38
Standard	355	9	26	65
Twelve Mile	3,442	8	46	46
Beacon	13,520	3	35	62

A sample of 100 mature cones from the four study areas in 1985 averaged only 9.4 sound of 104.5 potential seeds (table 6). Insects damaged or destroyed 43.4 of these seeds, 40.1 were hollow, 9.3 were abnormal, 2.3 had malformed embryos. The cone maggot most frequently caused damage within cones, followed by the woolly aphid and the scale midge. Feeding by cone maggot larvae left spiral tunnels around the axes. The condition of the seed (sound, hollow, etc.) before damage was obscured by this feeding. An examination of only undamaged cones and of cones damaged only by cone maggot, by woolly aphid, or by scale midge, gave a better understanding of the impact of each insect on viable seed.

Table 6.--Analysis of 100 mature western larch cones from Meadow, Standard, Twelve Mile, and Beacon study areas. Data shown as average number and range and $S_{\bar{x}}$ of seeds per cone and percent germination of total and potentially sound seed. From Shearer and Theroux (in press)

Condition	Average and range		$S_{\bar{x}}$
Damaged	43.4	(0-131)	3.8
Empty	40.1	(2-105)	2.4
Abnormal	9.3	(0- 67)	0.9
Malformed embryo	2.3	(0- 22)	0.4
Potentially viable	9.4	(0- 56)	1.2
Total	104.5	(52-158)	2.1
Germinated seed	7.9	(0- 56)	1.1
percent of total	7.6		
percent of potentially viable	84.2		

Cones without insects had no damaged seeds (table 7). Cones that were infested only by cone maggot larvae, however, averaged 85 (79 percent) damaged seeds; cones with only woolly aphids averaged 33 (33 percent) damaged seeds, and cones with only scale midges averaged 17 (17 percent) damaged seeds (table 7). Undamaged cones had about 14 (16 percent) seeds that were abnormal or the embryos were malformed; those with cone maggots had 5 (5 percent); those with woolly aphids 11 (11 percent); and those with scale midges 18 (18 percent). Cones with no insects had 21 (24 percent) potentially viable seed contrasting to 2 (2 percent), 5 (5 percent), and 14 (14 percent) for cones infested only by cone maggots, only by woolly aphids, and only by scale midges, respectively.

SUMMARY

In 1985, the number of seed cones generally increased as average spacing increased. Cone production was so low in 1986 that no pattern was evident. Unthinned trees had neither new nor old seed cones in 1985. The least productive site produced the fewest seed and pollen cones, while the more productive sites produced the most cones.

Frost caused the greatest reduction in cone potential by killing all cones within four of the nine stands examined in 1985 and within nine of the 11 stands examined in 1986. One stand escaped frost-caused cone mortality both years. A cone maggot caused heavy cone mortality at the five sites least affected by frost in 1985 and was present in cones collected in 1986. A woolly aphid caused some cone mortality in 1985 but none in 1986. A cone maggot, a woolly aphid, and a scale midge caused seed mortality in mature cones in 1985. Results from 1986 were not available. In 1985, cones with no insect damage averaged 24 percent sound seed, compared to 2, 5, and 13 percent sound seed in cones damaged only by a cone maggot, woolly aphid, or scale midge, respectively.

CONTINUING RESEARCH

At least three more field seasons will be devoted to documenting cone production for both studies and causes of cone mortality in study 2. About 1989, when the fieldwork on these studies may terminate, we will begin to determine the effects of cultural treatments on cone production of western larch. This effort will interest managers of seed production areas and seed orchards. In addition, the current studies will identify other factors we should study in greater depth.

Results from our studies will help predict where natural regeneration of larch should succeed and where artificial means are necessary to ensure maintaining the species it in forest stands.

Table 7.--Analysis of mature western larch cones by cause of damage. Data shown as average number and range and standard error of the mean ($S\bar{x}$) of seeds per cone and percent germination of total and potentially sound seed. From Shearer and Theroux (in press)

	Cause of damage							
	Undamaged n=11		Woolly aphids n=7		Cone maggots n=26		Scale midges n=32	
Condition	Avg.	Sx	Avg.	Sx	Avg.	Sx	Avg.	Sx
Damaged	0 (0)	0	33 (3- 99)	14	85 (53-131)	4	17 (0- 99)	4
Empty	52 (22- 78)	5	51 (17- 87)	10	16 (2- 46)	2	53 (17-105)	3
Abnormal	12 (2- 20)	2	9 (5- 16)	2	4 (0- 12)	1	14 (2- 67)	2
Malformed embryo	2 (0- 11)	1	2 (0- 5)	1	1 (0- 2)	T	4 (0- 22)	1
Potentially viable	21 (2- 56)	5	5 (0- 15)	2	2 (0- 11)	1	14 (0- 47)	2
Total	87 (52-112)	7	100 (82-130)	7	108 (68-144)	4	102 (58-158)	4
Germinated seed	20 (2- 56)	5	5 (0- 15)	2	2 (0- 10)	1	13 (0- 47)	2
percent of total	23		5		2		13	
percent of potentially viable	96		100		85		90	

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Tree Improvement Comes of Age in the Pacific Northwest: Implications for the Nurseryman[1]

Richard F. Piesch[2]

Abstract.--Tree improvement programs in the Pacific Northwest have reached the stage of supplying limited, but ever increasing, quantities of genetically improved seed to nurseries for regional regeneration programs. With this seed comes opportunities as well as responsibilities for the nurseryman. This paper explores the role of the nurseryman in the capture, packaging and transfer of genetic gain potential in the integrated forest management system.

INTRODUCTION

The status of tree improvement today in the Pacific Northwest can be likened to a relay race. The tree improvement worker is nearing the end of the first lap, and is about to pass the baton onto the nurseryman. The handoff is critical, as is the race strategy. We are here today to give thought to both these elements, and to better understand how our concerted efforts will make our investment in tree improvement a winner.

In keeping with this theme, the objectives of today's presentation are threefold:

1) To briefly review the status of tree improvement in the region and its impact on regeneration programs.

2) To develop the concept of genetic gain, and its capture, packaging and transfer into an integrated forest management system.

3) To explore the role of the nurseryman in this system, and the opportunities he or she has to maintain or even enhance the gain potential of genetically improved planting stock.

THE DEVELOPMENT AND STATUS OF TREE IMPROVEMENT IN THE REGION

Tree improvement programs, as we think of them today with selection, breeding, testing and seed production functions, started in the Pacific Northwest in the mid-1950's. By 1960, several Douglas-fir seed orchards had been established, representing both federal and private organizations. During the 1960's, few new orchards were established. However, with the 1970's came a surge of activity, such that by 1980 at least 82 orchards, representing more than one dozen species, had been established (Wheat and Bordelon, 1980). This has risen to an estimated 90 orchards today, for which Douglas-fir accounts for more than one-half. There are approximately 1700 acres of Douglas-fir orchards, or about 75% of the total orchard acres for all species.

To support this very large production activity, much effort has been placed on selection of parents from natural stands. In the Douglas-fir region alone, close to 30,000 "Parent" or "Plustree" selections have been made. Douglas-fir accounts for about 26,000 of these. More than 700 genetic tests have been established, with the primary purposes of evaluating these selections as parent trees and/or providing advanced-generation selections.

Participation in tree improvement in the Douglas-fir region is broad-based, involving at least 40 private landowners, 1 Canadian and 3 U.S. federal agencies, 3 state agencies, 1 Canadian province and 3 universities. Although a few programs are independent, the majority are involved in IFA-PNW cooperatives (Wheat and Silen, 1982). The programs vary widely in their approaches, with different selection intensities, different approaches to seed production, and different levels of management and support. These differences in themselves have an impact on nursery practices and the management of improved seed, and will be discussed later in this paper.

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THE IMPACT OF TREE IMPROVEMENT ON REGENERATION PROGRAMS

In western Oregon and Washington, more than 11,000,000 acres are covered by a tree improvement program (Cafferata, 1985), and in coastal British Columbia, more than 2,000,000 acres.[3] Of this 13,000,000 total, approximately 263,000 acres are regenerated annually.

The impact of genetically improved seed on this annual planting stock requirement for some major programs are given in Table 1. Other programs not listed range from having no improved seed yet available to fully meeting their current planting stock requirements.

As Table 1 shows, nurserymen will be having a progressively higher proportion of genetically improved seed coming through their nurseries in the near future.

GENETIC GAIN: ITS INTEGRATION INTO A FOREST MANAGEMENT SYSTEM

To better understand what "improved" seed means to the nurseryman, we need to understand the concept of genetic gain and its integration into a forest management system. Since genetic gain comes from tree improvement, the goals of tree improvement must be defined. We can think of these goals as three interrelated functions:

1) To capture genetic gain potential.

2) To package and transfer this potential into a regeneration system.

3) To optimize the benefits of this potential in terms of product value, throughout the nursery, stand culture, harvest and utilization phases.

Two points need to be stressed here. First, we are dealing with gain potential. We may capture it at one stage, only to lose it at another. Thus, the onus of maintaining the gain potential transfers from the tree improvement worker to the nurseryman, to the silviculturist and to the forest land manager, much like the example of the relay race cited in the Introduction. Secondly, the word "optimize" is used rather than "maximize." Implicit in this distinction is the knowledge that economic constraints should and will play a role in seeking tree improvement benefits, a point which will be further developed later in this paper.

Table 1.--Impact of improved seed on regeneration programs for several representative organizations in the Douglas-fir region. [Acres regenerated with improved stock and percent of total annual planting stock requirements (PSR)].

	Current Levels		Future Projections		
Program	Acres	% PSR	Acres	% PSR	Year
IFA-PNW Coops	18,000	12[1]	120,000	75	1995
(Government and Private)	80,000	50[2]	160,000	100	2000
British Columbia (Crown and Private)	9,900	29	30,000	85	1995
Weyerhaeuser	19,000	62	40,000	100	1992

[1] Five-year average through 1984.
[2] Projected 1986 sow only. Reflects exceptional 1985 cone crop expectations.

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[3] Konishi, J. 1986. Personal Communication. B.C. Forest Service, Reforestation Division. Victoria, B.C. Canada

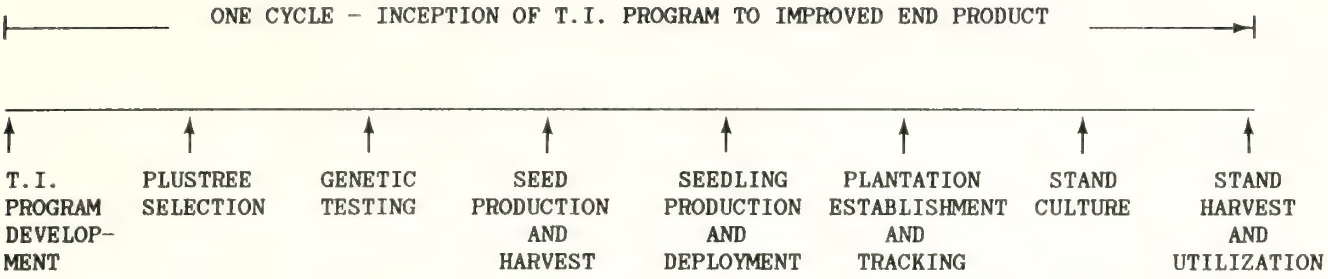
ONE CYCLE - INCEPTION OF T.I. PROGRAM TO IMPROVED END PRODUCT
T.I. PROGRAM DEVELOPMENT
PLUSTREE SELECTION
GENETIC TESTING
SEED PRODUCTION AND HARVEST
SEEDLING PRODUCTION AND DEPLOYMENT
PLANTATION ESTABLISHMENT AND TRACKING
STAND CULTURE
STAND HARVEST AND UTILIZATION

Figure 1.--Our key leverage points to capturing, maintaining or enhancing genetic gain potential.

We have many key leverage points at which we can capture, maintain and enhance genetic gain potential, from the time a tree improvement program is planned to the time the end product is utilized (Figure 1).

The first four leverage points, i.e. T.I. Program Development through Seed Production and Harvest, largely determine the amount of potential that can be captured. The last five, i.e. Seed Production and Harvest through Stand Harvest and Utilization, determine largely how much potential is maintained. The Seedling Production (Nursery) phase can also effectively enhance the potential, since the nurseryman manages populations of seeds and seedlings, and as such, can manipulate gene frequencies in a directed way. For today, we will restrict our discussions to those leverage points most directly affecting nursery management, i.e. Seed Production and Harvest, Seedling Production and Deployment, and Plantation Establishment and Tracking.

IMPACT OF SEED PRODUCTION SYSTEM ON NURSERY MANAGEMENT

Both gain potential and seed availability will impact the management of improved seed in the nursery, and both depend on the type of tree improvement program followed. Seed derived from a "Parent Tree" program (i.e. selected trees in natural stands used for seed supply) will probably become available sooner, have less gain potential and be less dependable in supply year-to-year as compared to seed derived from a seed orchard program. A clonal orchard typically will produce sooner, and with a higher gain potential, than a seedling seed orchard. A rogued orchard will have a higher gain potential than a non-rogued orchard but at the expense of total seed production at various times during the production period.

It is important to recognize here that a seed orchard is not simply a seed orchard, nor is the objective of an orchard simply to provide genetically improved seed. Rather, the orchard should strive to strike a balance between maximizing genetic gain potential and meeting planting stock requirements. The seed orchard and the seed it produces represent a very dynamic system. As the quantity of seed produced increases, so should the gain potential, due to the increasing ability to rogue inferior parents or selectively harvest from the best.

Perhaps the key leverage point at the seed orchard affecting the nursery system is seed harvest strategy. The strategy adopted for harvest sets the stage for the deployment strategy and directly affects nursery management practices. Some of the harvest options available to the orchardist include:

- whole orchard bulk mixes;
- specific mixes based on:
    - seed zone / elevation
    - tested vs. non-tested status
    - elite vs. average
- family level collections (i.e. seed from individual clones.

Whole orchard bulk mixes will result in the largest seedlot size possible, but will also have the lowest gain potential. As we progress down through the options we tend to decrease lot size (fewer parents or trees contributing per seedlot) but we also increase our ability to maximize gain potential. The orchard harvest strategy therefore will impact nursery management by determining seedlot size and gain potential, which in turn will affect nursery costs and practices.

THE ROLE OF THE NURSERYMAN IN MAXIMIZING GAIN POTENTIAL

Within the nursery system there are several key leverage points for maintaining or enhancing genetic gain potential. Among these include:

- ability to manage small lots
- potential to sow by family
- optimum utilization of improved seed
- cost control
- tracking and follow-up

Small Lot Management

The ability to deal with small lots is essential to maximizing gain potential. As discussed earlier, there is a general inverse relationship between gain potential and lot size. Thus, smaller lots can be considered opportunities rather than liabilities, as is generally the case. Two questions the nurseryman must address are (1) what constitutes the minimum sized lot that can be efficiently managed operationally? and (2) what changes in nursery technology might be possible to change this? Answers to these questions will bear on the orchard harvest strategy chosen.

Family Sowing

Sowing by individual family represents the probable extreme case of small lot management with its associated high gain potential. In addition to this attribute, there are several other benefits from family sowings. By sowing "pure" families rather than mixtures of families, the chance for disproportionate culling could be avoided. Progeny test data have shown that some families, although excellent performers over time, start very slowly in the nursery. For example, families B and C in Table 2 ranked 40 and 39, respectively, of 45 in height at the end of the first year in the greenhouse. However, by year 8 of the field progeny test, they had risen to rank 2 and 3. Both would have been largely culled from a mixed lot after one year in the nursery, even though both proved superior performers in the field.

This example well illustrates how differential culling standards may be appropriate, particularly in those cases where subsequent field performance potential has been demonstrated. Differential culling standards here translates into improved yields, which means an increased contribution by superior families to the regeneration program.

Table 2.--Family performance rank in height over time. Weyerhaeuser Company Twin Harbors Progeny Test.

	Rank								
	After One Year in Greenhouse	Year in Test							
Family		1	2	3	4	5	6	7	8
A	27	14	9	8	3	2	2	1	1
B	40	40	22	6	4	3	1	2	2
C	39	20	5	7	7	7	8	3	3
D	29	7	2	1	1	1	3	4	4
E	5	2	4	2	2	4	4	5	5
W	45	45	45	44	43	43	43	42	41
X	37	38	38	40	41	41	41	41	42
Y	35	39	41	42	42	42	42	43	43
Check[1]	44	44	44	43	44	44	44	44	44
Z	42	41	43	45	45	45	45	45	45

[1] Check is mean of two field check seedlots.

Traits other than growth response, e.g. frost tolerance, susceptibility to herbicides, etc., also may be more observable when seeds are sown as families rather than mixes. Thus, family sowings become the key to identifying and managing unique opportunities or problems at the nursery stage.

Another benefit of family sowing is that it allows for the deployment option of family block plantations. While this option is practiced little in the Pacific Northwest, it is the main deployment strategy on large forest ownerships in the southeast United States. Limiting its use at present in the Pacific Northwest are the unknowns relative to opportunity and risk.

Optimum Utilization of Improved Seed

Perhaps the key leverage point in the nursery to maximizing genetic gain potential is the acceptance and use of a nursery system, including alternative stock types, which converts the most seed to plantable seedlings. While 100% oversow factors are not unusual in a conventional nursery program, we should not be content to lose one-half of our high cost, improved gain potential seed to nursery falldown and culling. While some level of culling will probably always be appropriate, other factors than genetic growth potential contribute to this falldown. Also, as Table 2 illustrated, genetic potential may not express itself yet in the nursery phase.

Economics of Improved Seed Utilization

In weighing the alternatives for improved seed utilization, the economics of the system must be considered. Decisions to maximize seed utilization are not "justifiable at any cost." One approach to economic evaluation is the Present Value : Cost ratio, an approach commonly used for long-term investment decisions in forestry. To determine a PV : Cost ratio, several factors must be considered and quantified.

- Incremental yields, i.e. how many more plantable trees per pound of seed are achievable.
- Incremental costs to produce this incremental yield.
- Estimated incremental gain of improved seed; which may vary by harvest strategy or level of improvement, and will be estimated by genetic test results.
- Estimated value, e.g. $'s/acre, of incremental gain; which may vary by site class and can be estimated from economic and growth and yield models.

Once these factors have been estimated, the PV : Cost ratio can be calculated. A hypothetical example follows:

Incremental Cost Per Acre

= (Trees per Acre/1000) x

(Incremental Cost per K Trees) x

(Improved Yield Factor)

= $10

Incremental Value Per Acre

Case I Improved Seedlot 1, Site I = $40

Case II Improved Seedlot 1, Site II = $30

Case III Improved Seedlot 2, Site I = $20

Case IV Improved Seedlot 2, Site II = $10

PV : Cost Ratio

Case I = 4 : 1

Case II = 3 : 1

Case III = 2 : 1

Case IV = 1 : 1

The calculated PV : Cost ratios must be then compared to values considered as investment decision thresholds by your organization. PV : Cost ratios equal to or above these thresholds would suggest a sound economic decision within your organization to improve yields while accepting the increased associated costs.

Cost Control

While cost control is essential in any nursery operation, it has a special significance in maximizing genetic gain potential as it pertains to improved seed utilization. The lower the cost to produce a given stock type, the more opportunity there is to increase yields within given economic constraints. Reduced costs can directly impact the PV : Cost ratio just described, thus potentially qualifying additional seedlots for the improved-yield system. For example, if the incremental cost per acre was reduced from $10 to $7, and the organization's threshold value for investment was 4:1, all Site II land would now qualify for Improved Seedlot 1 being grown in the improved-yield system. Genetic gain potential would be enhanced because a higher proportion of plantation acres would be impacted with improved seed.

Tracking and Follow-up

This leverage point is certainly not restricted to the nursery phase, as the genetic components of any seedlot must be trackable from the orchard through the nursery to the plantation, as well as from the plantation back to the orchard. Nurseries and plantations should be considered as extensions of the genetic testing program. Both time and number of traits measured are limited in genetic tests, and little or no testing is possible for unique and infrequent climatic events.

The nurseryman's role in this "extended testing" is vital. Not only must opportunities or problems related to improved seed be identified, but also they must be reported and followed up. Without this continual awareness by all those involved with improved stock, the genetic gain potential will most certainly be compromised.

CONCLUSIONS

Seed from tree improvement programs are becoming a major component of nursery sow programs in the Pacific Northwest, and within the next decade will become the exclusive component for many programs. Nurserymen are a part of the tree improvement effort and have a vital role in maintaining or enhancing the genetic gain potential of improved planting stock. Of the many opportunities for the nurseryman to impact genetic gain potential, perhaps his greatest contribution will be in optimizing the yields of improved seedlings. In so doing, he will positively effect the gene frequencies of desired traits in the integrated forest management system.

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Stratification Reduced Germination of Ponderosa Pine Seed Collected in New Mexico and Southern Colorado[1]

Thomas M. Smith[2]

Abstract.--The 1983 seed year produced extremely low unstratified germination percentages for ponderosa pine (Pinus ponderosa, Rocky Mountain form) on Bureau of Indian Affairs administered lands in New Mexico and Southern Coloardo. Stratification reduced this percentage i nearly every case and did not reduce the germination time.

INTRODUCTION

Cones collected on Bureau of Indian Affairs administered lands in New Mexico and Southern Coloardo in the fall 1983 yielded the average amount of clean seed per bag, much larger seed, and extremely low unstratified germination. Excessive mold was noted on every sample, but seed surface fungicide treatments did not increase germination. X-rays indicated full seed.

Twenty-two samples representing all areas of collection were retested in early 1985. A germination comparison of unstratified, and stratified for 30,45,60,75 and 90 days was done at the National Tree Seed Lab in Dry Branch, Georgia and compared to unstratified, and stratified germination for 31,45 and 55 days done at Bureau of Indian Affairs Greenhouse Facility located in Albuquerque, New Mexico.

DISCUSSION AND RESULTS

The 871 half full burlap sacks of ponderosa pine cones collected from October 12, 1983 through December 8, 1983 throughout New Mexico and Southern Colorado yielded 514.8 lbs. of clean seed. The yield per bag was about average, but the approximately 11,000 seeds per pound was much better than the normal of 14,000 seeds per pound. The average unstratified germination was approximately 35 percent as compared to the normal unstratified germination of between 85 and 90 percent.

Initial testing was performed at the National Tree Seed Lab in Dry Branch, Georgia in 1984.

Excessive mold was noted on every sample. Dipping in neither bleach nor captan at the recommended rates improved germination. There was no correlation between germination percent and date of collection.

TABLE 1, details the results from stratified and unstratified germination tests from the 1985 test at the National Tree Seed Lab.

TABLE 1, NATIONAL TREE SEED LAB GERMINATION COMPARISON

	Germination (%)					
ACCESSION		Stratification (days)				
NUMBER	Unstratified	30	45	60	75	90
83B01	46	29	37	40	35	36
83B02	55	34	32	38	25	37
83B04	29	14	16	20	17	17
83B06	24	4	6	12	11	11
83B07	49	23	25	25	30	29
83B08	33	14	15	17	15	14
83B09	14	6	5	5	8	7
83B10	47	21	19	26	27	29
83B11	41	26	19	3	25	27
83B12	27	17	20	21	21	18
83B14	24	14	6	10	8	9
83B15	54	48	41	39	48	50
83B16	27	21	13	22	19	23
83B17	42	39	33	36	34	36
83B22	28	14	14	15	16	15
83B25	27	16	16	19	15	17
83B28	49	30	32	33	33	35
83B29	37	31	25	37	29	23
83B30	41	30	28	29	29	32

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[1] Paper presented at Western Forest Nursery Council Meeting [Tumwater, Washington August 11-15, 1986.]

[2] Thomas M. Smith is the Forest Development Officer at Bureau of Indian Affairs, Southern Pueblos Agency, Albuquerque, New Mexico.

83B31	48	35	37	42	42	50
83B32	25	22	27	26	23	29
83B34	70	52	54	51	48	50

The report sheets indicated that the first weeks germination percentages were higher in the stratified samples than the unstratified, however by the end of the second week germination was virtually finished in all samples, stratified and unstratified. With the exception of 83B29 stratified for 60 days, germination was reduced in all cases with stratificatin.

TABLE 2, details the results from stratified and unstratified germination tests done at the Bureau of Indian Affairs Greenhouse Facility in Albuquerque, New Mexico.

TABLE 2, BUREAU OF INDIAN AFFAIRS GERMINATION COMPARISON

	Germination (%)			
ACCESSION		Stratified		
NUMBER	Unstratified	31	45	55
83B01	28	10	11	12
83B02	19	8	12	11
83B04	5	3	1	6
83B06	2	4	3	4
83B07	14	5	7	7
83B08	4	1	1	3
83B09	1	1	1	1
83B10	5	2	0	6
83B11	14	6	8	11
83B12	6	3	2	3
83B14	2	1	1	3
83B15	18	18	15	18
83B16	2	1	2	4
83B17	20	15	11	15
83B22	5	2	1	1
83B25	3	1	3	5
83B28	28	15	11	13
83B29	9	10	7	6
83B30	10	10	6	8
83B31	12	9	6	10
83B32	10	7	3	7
83B34	54	37	28	28

The Bureau of Indian Affairs Greenhouse Facility in Albuquerque, New Mexico is a production greenhouse. Unstratified seed will normally begin cracking 4 days after sowing. The only equipment available for stratification is a refrigerator, which is subject to temperature fluctuations during normal use. Temperatures were maintained between 34F and 38F.

Prior to stratification the seed was soaked for 24 hours and then dipped in captan at the rate of one tablespoon per gallon. Stratification was terminated at 55 days because the seed was beginning to crack.

The reason for the large reduction in germination between the seed lab and the greenhouse can not be explained at this time.

Stratification increased germination over unstratified germination in Accession Numbers 83B04,83B06,83B10,83B14,83B25,83B29 and stayed the same in 83B09,83B15 and 83B30. Germination is so low in all cases, however, that the value stratification is questionable, as is the use of this seed.

CONCLUSIONS

This experiment was done in a effort to increase abnormally low germination. Stratification reduced germination in most instances and did not reduce the germination time in those samples tested here.

It should be stressed that the 1983 germination percentages were usually low, and further research on the value of stratification of ponderosa pine in the southwest should be conducted.

Comparison of Seed Stratification Methods for Western White Pine[1]

CHARLES GANSEL[2]

Better seed stratification is needed to break the dormancy in western white pine, to obtain more rapid and uniform germination. Four stratification methods were compared. Warm/cold stratification was superior to cold stratification methods, especially for low germinating lots.

In the past, the efficiency of the blister rust testing program at the Dorena Tree Improvement Center has been limited by the low germination percentages exhibited by some of the seedlots selected for the testing program. Germination percentage varies greatly among seedlots, ranging from 0 to almost 100 percent. Approximately 15 percent of the seedlots sown for testing purposes were in the zero to marginal range. These lots will probably not have enough surviving seedlings to provide a sufficient base for rust testing. Lack of sufficient base due to poor germination has been an ongoing problem at Dorena. Overcoming this problem would increase the efficiency of the rust testing program by an estimated 10 to 15 percent.

The low germination is not due to low viability or poor germination but to dormancy, and is expressed in large numbers of firm seeds, which do not germinate. We are looking for a method that will overcome dormancy. Dorena personnel have performed a number of small studies over the past few years aimed at developing stratification techniques which will result in higher overall germination percentages among seedlots. Such techniques have been worked out fairly successfully for sugar pine, but western white pine has been less tractable. Current research has not attacked this problem to a degree that would benefit the Dorena program. Further study is needed to upgrade stratification techniques.

BACKGROUND

The current method of stratification being used at Dorena consists of a 48 hour soak in 1 percent hydrogen peroxide (H_2O_2) followed by 120 days chilling at 34-38°F. This does not appear to be sufficient for some western white pine seed lots to overcome germination blocks. This problem is not limited to Dorena. A survey of other nurseries in the northwest indicated poor germination in some lots. Wind River Nursery soaks the seed for 24 hours and then puts it in cold stratification for 90 to 120 days. They have, however, gone to fall sowing for western white pine to improve stratification. J. Herbert Stone Nursery uses a 24-48 hour running water soak, followed by 100 days cold stratification in a nylon mesh bag layered in peat. Coeur d'Alene Nursery soaks the seed in a home laundry bleach (2 parts bleach to 3 parts water) for 10 minutes, then rinses them for 4 days under running water, followed by cold stratification in the refrigerator for 45 to 50 days.

Past Dorena studies indicate that a different combination of H_2O_2 concentration and length of soak may yield better results. Research by Anderson and Wilson (1966) and D.W. Taylor (personal communication) suggests that a combination of warm stratification at room temperature, followed by cold stratification, would be more effective in promoting germination than cold stratification alone.

Other factors that may affect germination are the use of infrared irradiation (Works and Boyd, 1972) and seed moisture content (Edwards, 1981). Recent work indicates that relatively small variations in moisture content of the seed during stratification may lead to significant differences in germination. Edwards (1981) has found that the optimum germination in *Abies grandis* occurs when seed is dried to 35 percent moisture content following the soak treatment. McLemore and Burnett (1968) report that dormancy was least in *Pinus taeda* seeds when stratified at a moisture content greater than 20 percent. However, the optimum moisture content for stratifying western white pine seed is as yet unknown.

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[1] Paper presented at the Western Forest Nursery Council Meeting, Tumwater, Washington, August 12-15, 1986.

[2] Durena Tree Improvement Center, Cottage Grove, OR.

OBJECTIVE OF STUDY

The objective of this study was to compare different stratification methods for western white pine to see which would result in more rapid and uniform germination among families. Improving the uniformity of germination should lead to increased efficiency in Dorena's rust testing program. Moisture uptake was a problem that this study will address. Cold stratification vs. warm/cold stratification would be compared as well as a 1% H_2O_2 soak vs. household bleach soak followed by rinsing for four days in running water.

METHODS AND MATERIALS

Twenty families were used in this study. Five families with less than 50% germination in previous tests and five with greater than 50% germination, along with 10 families of unknown performance. All methods of stratification received a 48 hour soak except those lots which were washed for 4 days in running water. All seed had been stored in the freezer at 0°F. Fresh seed may give entirely different results. Total length of stratification for all lots was 120 days.

The following methods of stratification were compared in this study.

Method 1. Dorena operational stratification.
A. 48 hour soak in 1% H_2O_2.
B. Drain.
C. Cold stratification at 34-38°F. for 120 days.

Method 2. Warm/cold stratification.
A. 48 hour soak in 1% H_2O_2.
B. Surface dry.
C. 30 days warm stratification at 50°F. in growth chamber.
D. Dry to 30-35% moisture content and then put into cold stratification at 34-38°F. for 90 days.

Method 3. University of Idaho Method.
A. Soak seed 10 minutes in a solution containing 2 parts sodium hypochlorite (clorox) and 3 parts water.
B. Rinse seed in flowing water for 4 days.
C. Drain.
D. Place seed in nylon mesh bag and layer in peat at 34-38°F. for 120 days.

Method 4. Modified University of Idaho Method.
A. Saok 48 hours in 1% H_2O_2 solution.
B. Drain.
C. Place seed in nylon mesh bag and layer in peat at 34-38° for 120 days.

The seed were sown in large flats (40"X48"X12") filled with "Forestry Mix" growing media. Only sound seed were sown. Two seed were planted per spot and spots were about 4" apart. There were 2 replications of 5 planted spots per family or 20 seed sown per family per treatment method. The seed was sown on March 31, 1985, and germination was recorded periodically throughout the next 48 days.

RESULTS AND CONCLUSIONS

Results from the water uptake portion of the study are presented in Table 1.

Table 1. Water Uptake in Stratification Test

Family Number	Tree Number	Weight of 20 seed (grams)	Moisture content after 48 hr. soak (percent)	Moisture content after warm strar. (percent)
1	119-01167-006	0.452	43.6	44.0
2	119-01167-007	0.358	39.1	41.5
3	119-03124-382	0.329	35.1	42.7
4	119-03124-390	0.361	34.2	32.5
5	119-06023-513	0.302	31.7	35.5
6	119-06024-612	0.393	32.3	32.3
7	119-06025-526	0.422	33.3	34.4
8	119-06124-661	0.387	32.7	36.7
9	119-06124-662	0.371	32.9	41.4
10	119-06125-538	0.246	37.7	42.0
11	119-15043-920	0.434	31.4	38.4
12	119-15045-935	0.352	34.7	39.5
13	119-17113-337	0.324	36.5	47.0
14	119-17113-340	0.312	37.5	40.5
15	119-17115-715	0.395	33.6	36.8
16	119-17115-816	0.287	36.9	46.2
17	119-18035-393	0.437	27.0	36.7
18	119-18034-397	0.412	29.4	35.3
19	119-20046-025	0.466	35.6	45.9
20	119-20046-044	0.543	33.9	34.6

It appears that water uptake was not a problem in this study. The moisture content of the seed in storage was approximately 6%. Moisture content of the seed after the 48 hour soak ranged from 27.0 to 43.6%. The moisture content in all lots appears to be adequate for germination, as the lot with the least moisture content germinated about as well as the lot with the most moisture (85 vs. 90% respectively).

Results of germination from the four stratification methods are presented in Tables 2 - 5.

Table 2. Rate and Proportion of Germination of Seed Following Stratification by Method 1: The Dorena Operational Procedure.

Date:	4/19	4/25	5/6
Day No.	20	30	41
Family Number	Number of emergent seedlings per 20 planted seed.		
1	12	13	18
2	9	10	10
3	11	14	17
4	16	16	18
5	0	0	2
6	12	13	13
7	2	3	4
8	4	5	9
9	10	11	16
10	1	2	6
11	15	16	19
12	18	19	19
13	10	13	16
14	3	3	5
15	10	12	15
16	13	15	16
17	13	14	17
18	17	17	18
19	15	15	15
20	20	20	20
OVERALL %	53	58	68

Table 3. Rate and Proportion of Germination of Seed Following Stratification by Method 2: Warm/Cold Stratification.

Date:	4/19	4/25	5/6
Day No.	20	30	41
Family Number	Number of emergent seedlings per 20 planted seed.		
1	13	14	17
2	11	14	15
3	15	17	19
4	18	19	20
5	0	1	16
6	14	15	15
7	12	17	19
8	12	17	20
9	13	16	18
10	5	8	18
11	8	16	17
12	14	16	18
13	13	17	18
14	14	17	20
15	9	12	19
16	3	10	20
17	9	15	19
18	11	17	19
19	16	17	17
20	12	18	20
OVERALL %	56	73	91

Table 4. Rate and Proportion of Germination of Seed Following Stratification by Method 3: University of Idaho Method.

Date:	4/19	4/25	5/6
Day No.	20	30	41
Family Number	Number of emergent seedlings per 20 planted seeds.		
1	11	13	15
2	11	11	12
3	9	14	16
4	15	15	15
5	0	1	6
6	12	16	18
7	5	6	7
8	8	9	9
9	9	11	12
10	7	11	12
11	11	14	18
12	19	19	19
13	12	13	16
14	5	5	10
15	11	16	20
16	14	18	19
17	13	15	19
18	17	19	19
19	20	20	20
20	20	20	20
OVERALL %	57	67	76

Table 5. Rate and Proportion of Germination of Seed Following Stratification by Method 4: Modified University of Idaho Stratification.

Date:	4/19	4/25	5/6
Day No.	20	30	41
Family Number	Number of emergent seedlings per 20 planted seeds.		
1	9	10	15
2	7	8	10
3	7	9	14
4	13	13	15
5	0	1	2
6	10	11	13
7	4	7	8
8	8	8	8
9	11	14	15
10	7	8	11
11	14	15	17
12	20	20	20
13	13	14	17
14	3	3	6
15	15	18	18
16	17	17	20
17	11	12	17
18	16	17	19
19	17	17	18
20	20	20	20
OVERALL %	56	61	71

Germination at 41 days appears to be the best time for comparison. Little change was noted after that time and seed which had germinated by that time would be useful in the rust test. Overall germination for Methods 1-4 are 68, 91, 76, and 71 respectively. The Warm/Cold Stratification Method does stand out above the rest.

The important issue at Dorena is "how well do the poorest lots do with Method 2, and does it have any adverse effect on the best germinating lots". The 5 best germinating lots are compared with the 5 poorest germinating lots. Results are presented in Table 6.

Table 6. Comparison of Germination in Best and Poorest Families.

Five Best Germinating Families

Family Number	Stratification Method (Number of Germinates at 41 Days) 1	2	3	4
4	18	20	15	15
11	19	17	18	17
12	19	18	18	20
18	18	19	19	19
20	20	20	20	20
Percent	94	94	90	91

Five Poorest Germinating Families

Family Number	1	2	3	4
5	2	16	6	2
7	4	19	7	8
8	9	20	9	8
10	6	18	12	11
14	5	20	10	6
Percent	26	93	44	35

There appears to be very little difference in germination in the best germinating lots, regardless of stratification method used. Method 2 does not appear to have an adverse effect on lots which are easy to germinate. When stratification methods were compared for the 5 poorest germinating lots, Dorena's method had only 26% germination. These lots would probably be lost in rust test, as they would have insufficient base for a valid test. The warm/cold stratification method brought these lots up to the same germination percentage as the best germinating seed lots (93%). The germination using the modified University of Idaho method (35%) was 9% better than the Dorena method (26% germination). The germination by the University of Idaho method (44%) was 9% better than the modified Idaho method (35% germination). The largest improvement in germination was obtained by use of the warm/cold stratification methods on the poorest germinating lots. This 67% increase in germination over Dorena's operational method is highly significant.

These results indicate that significant improvement can be made in seed germination by using warm/cold stratification method. We now have a good method to use for stratification of western white pine seed, but additional fine tuning may yield further improvements.

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Excised Embryo Test for Western White Pine[1]

William G. Johnson[2]

Abstract.--The excised embryo test provides accurate estimates of viability for Western White Pine (*Pinus monticola*) seed in 10 days.

INTRODUCTION

Western White Pine (*Pinus monticola*) seed is dormant and needs three months stratification and one month incubation for laboratory germination testing. Often the seed dormancy is still not overcome and the germination test is substantially below the germination in the nursery beds. A quick viability test should be used for deep dormancy species. The excised embryo test has been used on tree seed to determine viability since 1934 (Heit 1955) and has a close correlation with actual germination.

THE EXCISED EMBRYO TEST

The excised embryo test is quick, seven to ten days, and accurate. It works well on Western White Pine (*Pinus monticola*). The test is performed on 200 seed per lot as follows:

1. Surface sterilize the seed.
2. Cut 1 mm off the radicle end of the seed.
3. Soak the seed in water 18 hours.
4. Cut the seed on both sides of the embryo.
5. Pry open the seed to expose the embryo.
6. Remove the embryo with a needle.
7. Incubate the embryo nine days at 20°C.

Live embryos will spread open the cotyledons and green up. Dead embryos will deteriorate.

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[1] Paper presented at the Western Forest Nursery Council Meeting, Tumwater, Washington, August 12-15, 1986.

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Nursery and Field Evaluation of Compost-Grown Coniferous Seedlings[1]

Mark Coleman[2], Joan Dunlap[2], David Dutton[3] and Caroline Bledsoe[2]

INTRODUCTION

An essential part of forest tree nursery culture is the use of organic amendments. Organic matter maintains soil characterisitcs like low bulk density, high water and nutrient holding capacities, improved soil structure and optimal environments for beneficial rhizosphere microorganisms (nitrifying bacteria, mycorrhizae, etc., Davey and Krause, 1980). Common organic amendments include green manure from cover crops, sawdust and peatmoss. Unfortunately, all have a high carbon to nitrogen ratio, may cause net nutrient immobilization and may release phytotoxic compounds. Sawdust and peatmoss availability are limited and used in other markets. Cover cropping requires additional nursery acreage. Composted material derived from manure, sawdust or spent mushroom compost results in less immobilization and little or no phytotoxic effects while still providing the desired organic input (Bledsoe 1981). Municipal sewage is an abundantly available organic nutrient source and has been favorably utilized in coniferous seedling production (Berry, 1985; Bledsoe and Zasoski, 1981). Addition of sludge provides supra-optimal nitrogen levels and will increase heavy metal levels in soils and plants (Bledsoe, 1981). However, the use of both sludge and sawdust, which have been composted together, combines the beneficial characteristics of each and mitigates the less desirable properties. The purpose of this experiment was to investigate the potential use of a sawdust-sludge compost in forest tree nurseries.

METHODS

Nursery

Nursery beds at the USFS Wind River nursery, Carson, WA were amended with compost (3:1 fir-hemlock sawdust: municipal sewage sludge from METRO, Seattle, WA). Additional characteristics of the compost, density 0.2 g/cm^3, 0.5% N, are found in Bledsoe (1981). Each of 12 nursery beds (330') were randomly selected for a particular compost treatment-tree species combination. The four compost treatments were 0, 2, 4 and 6 inch (0, 270, 528, and 805 cu. yds./acre, equivalent to 0, 513, 1000, and 1530 m^3/ha). The 3 tree species were Douglas-fir (*Pseudotsuga menziesii*), noble fir (*Abies procera*) and ponderosa pine (*Pinus ponderosa*). Compost was disced into the soil and seeds were sown in spring 1982. Seedlings were raised according to standard nursery procedures. In fall 1983, the 2-0 nursery stock was lifted and stored at 3°C until spring 1984 when they were outplanted at three sites.

Field

Douglas-fir was planted with hoedads on the southeast side of Mt. St. Helens in the blast zone on a 3000' elevation site (35% slope) which had been salvage-logged. Planting occurred 4 years after the May 18, 1980 eruption. Tefra, 12-20 inches deep, covered the surface. Roots of planted seedlings did not extend into mineral soil.

Noble fir was planted near Estacada, Ore. at an elevation of 3800' and slope of approximately 20%. The site had been logged in 1980, slash was hand piled and burned. Considerable brush covered the area. Seedlings were planted with hoedads in mineral soil.

Ponderosa pine seedlings were planted east of the Cascade crest at 3400' elevation, near Leavenworth, WA. The area had been tractor logged for mixed ponderosa pine and Douglas-fir and broadcast burned in fall 1983. Slopes were approximately 45%. Seedlings were planted with power augers in mineral soil.

The experimental design for all 3 sites was a randomized complete block. Each row consisted of seedlings from a single treatment with 4 treatments in each block. Rows and seedlings within rows were spaced 8' apart. The design was arranged as follows:

Site	Rows/ block	Blocks	Trees/ Row	Total
Mt. St. Helens	4	5	30	600
Estacada	4	12	12	576
Leavenworth	4	6	24	576

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Measurements and Analyses

Twenty-four seedlings from each compost treatment were measured for height, diameter and dry weight after 1 and 2 years in the nursery. Nutrient (N, P, K) and heavy metal (Zn, Cu, Pb, Ni, Cd) concentrations in roots were measured after 1 year on 4 pooled samples of 24 seedlings. Data were analyzed using a fixed-effects one-way ANOVA model for ponderosa pine, Douglas-fir and noble fir, respectively.

Field measurements of initial seedling height and diameter were made after planting in the spring of 1984. Seedling survival, height, and diameter were taken in the fall of 1984 and 1985. In these cases, a fixed-effect two-way ANOVA model was used for data analysis; compost treatment and blocks were the two factors used.

RESULTS AND DISCUSSION

Nursery: Growth

In general, Douglas-fir 1-0 seedlings were tallest while ponderosa pine had the greatest biomass (Table 1). Ponderosa pine seedlings responded favorably to compost application, with significant treatment effects on height and dry weight. Noble fir and Douglas-fir did not show any significant effects of compost treatment on growth parameters. Root collar diameter data are not presented since there were no significant treatment effects. Mean diameters were 2.4, 1.9 and 2.8 cm for Douglas-fir, noble fir and ponderosa pine respectively. Growth data from year 2 nursery phase are not presented since treatment effects for 2-0 seedlings in the nursery were similar to results from the outplanting phase.

When seedlings were lifted, average seedling shoot and root dry weights (g) were: Douglas-fir 3.6, 1.7; noble fir 2.5, 1.5; ponderosa pine 7.1, 1.7. Compost-grown seedlings were generally similar to control seedlings in height, diameter, shoot and root weights. However, compost-grown Douglas-fir and noble fir were 5-30% shorter than control seedlings. Compost-grown seedlings also had slightly higher root/shoot ratios than controls.

Nursery: Nutrients and Metals

Nutrient concentrations in 1-0 seedlings did not differ among species with 2 exceptions. Potassium levels in noble fir roots were high (1.3%) as were N levels in pine shoots (2.3%). Potassium levels were not altered by compost treatment so these data were not included. Average K concentrations were 0.64%, 1.0%, 0.62% for Douglas-fir, noble fir and ponderosa pine, respectively. The average root and shoot concentrations for all species combined were 1.5% and 1.9% (N), .26% and .24% (P). A significant increase in N and P due to compost application was observed for Douglas-fir and noble fir (Table 2). This enhancement in root and foliar P and in foliar N was not observed in pine.

Root heavy metal levels, averaged over all species, were 4.7 ppm for Zn, 6.0 ppm for Cu, 8.1 ppm for Pb, 3.4 ppm Ni and 1.0 ppm for Cd. Cadmium and Zn values were as much as 6 times greater in compost-treated seedlings but only the Cd values were significant (Table 3).

Table 1.--Height and biomass of conifer seedlings grown in compost-amended nursery beds for one year. Values are means of 24 samples. Values for each row followed by the same letter are not significantly different (alpha = .05)

	COMPOST TREATMENT				
Species	0"	2"	4"	6"	MEAN
Douglas-fir					
Height, cm	15. b	18. a	16. b	17. b	16.
Shoot, g DW	0.78 a	0.81 a	0.72 a	0.88 a	0.80
Root, g DW	0.39 a	0.32 a	0.31 a	0.35 a	0.34
Root/Shoot	0.51 a	0.41 b	0.44 b	0.42 b	0.44
Noble fir					
Height, cm	9.4 a	9.4 a	9.9 a	9.3 a	9.5
Shoot, g DW	0.31 a	0.36 a	0.37 a	0.31 a	0.34
Root, g DW	0.18 a	0.22 a	0.23 a	0.20 a	0.21
Root/Shoot	0.56 b	0.62 a	0.65 a	0.68 a	0.63
Ponderosa pine					
Height, cm	13. b	14. a	14. a	15. a	14.
Shoot, g DW	0.98 b	1.3 a	1.3 a	1.2 a	1.2
Root, g DW	0.45 b	0.61 a	0.56 a	0.61 a	0.56
Root/Shoot	0.49 a	0.48 a	0.43 a	0.50 a	0.48

Table 2. Percent nutrient concentrations in roots and shoots of seedlings grown in compost-amended nursery beds for one year. Values are means of four tissue analyses which were pooled samples from 24 seedlings. For root and shoot data, values for each row followed by the same letter are not significantly different (alpha = .05).

Species		Compost Treatment, Roots				Compost Treatment, Shoots			
		0"	2"	4"	6"	0"	2"	4"	6"
			- % -				- % -		
Douglas-fir									
	N	1.4 a	1.6 a	1.6 a	1.5 a	1.5 c	1.7 ab	1.8 a	1.5 b
	P	0.22 c	0.31 a	0.26 b	0.25 b	0.17 c	0.24 a	0.21 b	0.19 b
Noble fir									
	N	1.3 b	1.5 a	1.5 a	1.5 a	1.4 b	1.9 a	1.9 a	1.7 a
	P	0.19 b	0.25 a	0.25 a	0.25 a	0.20 b	0.27 a	0.26 a	0.25 a
Ponderosa pine									
	N	1.3 c	1.6 ab	1.8 a	1.5 b	2.1 a	2.2 a	2.3 a	2.4 a
	P	0.27 a	0.27 a	0.28 a	0.28 a	0.27 a	0.27 a	0.27 a	0.26 a

Table 3. Heavy metal content in ppm in roots of seedlings grown in compost-amended nursery beds for one year. Values are means of four tissue analyses which were pooled samples from 24 seedlings. Trace levels: Zn <.001, Ni <.01, Cd<.025 ppm. Values for each row followed by the same letter are not significantly different (alpha = .05).

Species	Compost Treatment				
	0"	2"	4"	6"	MEAN
		- ppm -			
Douglas-fir					
Zinc	T	0.88 a	1.8 a	3.2 a	2.0
Copper	5.0 a	5.7 a	5.8 a	4.4 b	5.2
Lead	4.4 a	6.2 a	5.2 a	4.4 a	5.0
Nickel	3.5 a	1.6 b	T	1.7 b	2.3
Cadmium	T	0.25 b	0.31 b	0.63 a	0.40
Noble fir					
Zinc	1.2 a	8.6 a	5.9 a	5.6 a	5.3
Copper	3.7 d	5.7 c	6.8 b	7.9 a	6.0
Lead	5.7 a	6.6 a	8.1 a	8.5 a	7.2
Nickel	2.2 a	1.6 a	T	1.7 a	1.9
Cadmium	0.56 b	0.63 b	1.8 a	2.1 a	1.3
Ponderosa Pine					
Zinc	4.8 a	11. a	5.1 a	T	6.8
Copper	7.2 a	6.1 a	7.3 a	7.0 a	6.9
Lead	12. a	11. a	9.1 a	16. a	12.
Nickel	6.0 a	5.9 a	5.8 a	6.7 a	6.1
Cadmium	0.50c	0.13 c	1.3 b	3.5 a	1.4

Other metals (Cu, Pb, Ni) did not accumulate above levels found in the control treatment, with one exception. In noble fir, copper levels steadily increased with increasing compost application rate.

There is little information on heavy metal levels in coniferous seedlings (Bledsoe and Zasoski 1981; Burton et al. 1984, 1986). Burton et al. 1984 found that root growth of Sitka spruce was inhibited at root concentrations >61 ppm Cd and 228 ppm Pb. Rolfe & Bazzaz (1975) measured inhibition of loblolly pine photosynthesis at similar tissue levels. The values for growth inhibition reported by Burton et al. (1984) were greater than 10 times the Cd and Pb concentrations measured in this study (Table 3). Wind River Nursery could accept more composted sludge before toxic levels of these two elements are reached.

Field

After one season's growth in the field, average survival ranged from 97% for Douglas-fir to 93% for noble fir and 88% for Ponderosa pine. For Douglas-fir, field survival of seedlings grown in compost-treated nursery beds was similar to control seedlings, except at the heaviest (6") application rate. Here, year 1 and year 2 survival was reduced from 93% (yr 1) to 84% (yr 2, Table 4). For noble fir, survival for compost-grown trees was slightly reduced in year 1, but this effect was not present by year 2. For ponderosa pine, survival effects were complex and seemingly unrelated to compost application rates. Survival was significantly reduced by the 2" and 6" treatments, but, inexplicably, survival in the control and 4" treatment was similar.

Douglas-fir height data show that growth in year 1 was much greater than growth in year 2.

Table 4. Two year height and survival data for 2-0 seedlings outplanted in spring 1984 on three sites in Washington and Oregon. Seedlings were previously grown at the Wind River nursery in beds amended with 0,2, 4 or 6 inches of compost. Values for each row followed by the same letter are not significantly different (alpha = .05).

Species, Site			Compost Treatments			
			0"	2"	4"	6"
Douglas-fir, Mt. St. Helens WA						
	Height, cm					
		Spring 1984	25.2a	20.4b	24.4b	21.9b
		Fall 1984	28.7a	24.0b	28.6a	23.9b
		Fall 1985	29.5a	25.8b	29.1a	25.0b
		Total Inc. %	17.5b	27.0a	19.5ab	14.7b
	Survival, %					
		Fall 1984	97.9a	99.3a	99.3a	93.4b
		Fall 1985	98.0a	95.9a	96.9a	84.2b
Noble fir, Estacada OR						
	Height, cm					
		Spring 1984	22.1a	13.7b	14.7b	14.5b
		Fall 1984	24.3a	15.9b	16.4b	16.5b
		Fall 1985	26.5a	18.1b	18.5b	18.8b
		Total Inc. %	20.6b	34.6a	26.9a	29.7a
	Survival, %					
		Fall 1984	99.2a	90.9b	87.2b	93.3b
		Fall 1985	95.4a	90.2a	85.9a	87.3a
Ponderosa pine, Leavenworth WA						
	Height, cm					
		Spring 1984	17.1a	18.3a	17.7a	16.7a
		Fall 1984	23.3a	20.7b	21.5b	19.3c
		Fall 1985	30.9a	27.4b	27.9b	25.8b
		Total Inc. %	81.7a	49.7b	58.3b	54.5b
	Survival, %					
		Fall 1984	97.5a	71.5c	100.0a	81.3b
		Fall 1985	93.5a	49.6c	83.8a	66.0b

Reduced second year growth may have been due to low nutrient availability in the tephra. Height increase for the 2 inch treatment was signficantly greater than the control treatment.

For noble fir, seedling heights were significantly lower in composted treatments, due to differences developed in the nursery. Percent height increase in compost treatments was significantly greater than controls, suggesting that compost-treated seedlings grew well in the field.

Ponderosa pine seedlings initially were identical in height, but later composted seedlings were shorter than controls. This trend was carried through the 1985 season. By the end of 1985, height increase in the control exceed 80%, whereas composted seedlings only grew 50%. Thus pine may not be suited for compost applications.

CONCLUSIONS

This study indicates that although initial growth of compost-treated nursery seedlings is improved, probably due to increased nutrient availability, subsequent nursery growth seems to be reduced. Nutrient immobilization in the high C:N compost may cause reduced growth. This process is no different than processes which occur after incorporation of traditional organic amendments such as peat, sawdust or cover crops. Despite the suspected immobilization effects of compost applications, especially on noble fir and ponderosa pine, the use of compost as an organic amendment appears promising. This is especially true for Douglas-fir which responded well to compost application as compared to controls. The optimal compost application rate for nursery phase seedlings appears to be either the 2" or 4" treatment. Six inch treatments produced consistently smaller seedlings than did the other compost treatments.

Use of sludge or composted sawdust/sludge mixtures should be applied with caution, since this study showed increased cadmium and zinc concentrations in roots of compost-grown trees. Addition of toxic heavy metals should be monitored, because these metals will accumulate in nursery soils. Fortunately, these environmentally hazardous materials often remain in the soil in close association with the applied organic compounds (Zasoski 1981). The problem with this soil retention is the possible buildup of these compounds to toxic levels. Lake et al. (1984) listed annual loading rates of Cd in Scandinavia - 22 g/ha, in the U.K. - 167 g/ha and in the U.S. - 1250 g/ha. Rather than discussing annual application rates, Bicklehaupt (1980) referred to cumulative levels for several different heavy metals. Cadmium levels should not exceed 20 kg/ha, while zinc levels should not exceed 1000 kg/ha for soils with high cation exchange capacities. In soils with lower cation exchange capacities, such as sandy soils or soils low in organics, these maximum levels are cut by a factor of 4. It therefore appears evident that use of sludge or composted sludge compounds in forest nurseries for organic inputs will require careful monitoring of soil and tissue levels so that toxic levels and seedling growth inhibition do not occur.

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First-Year Field Performance of Douglas-fir Seedlings in Relation to Nursery Characteristics[1]

Steven K. Omi, Glenn T. Howe, and Mary L. Duryea[2]

Abstract.--First-year field performance of 48 Douglas-fir seedling samples from six nurseries and nine seed sources was analyzed in relation to nursery measurements of seedling morphology, phenology, and vigor. Height at lifting accounted for 84 percent of the variation in first-year field height, while root dry weight and stem diameter at lifting had the highest correlations with first-year height growth ($r^2 = 0.43$ for both). A combination of phenological, morphological, and physiological characteristics yielded the best predictions of field performance (e.g., root dry weight at lifting combined with two vigor-test measurements accounted for 63 percent of the variation in first-year height growth). All correlations of nursery characteristics with first-year field survival were nonsignificant. First-year height growth and frequency of multiple leaders in the field were negatively related ($r^2 = 0.16$).

INTRODUCTION

High-quality seedlings are necessary for successful reforestation. Because morphological characteristics of seedlings are easy to measure, most nurseries grade their seedlings according to those criteria (Ritchie 1984, Thompson 1985). Recently, however, the physiological condition of a seedling has been emphasized as an important determinant of its ability to survive and grow in the field (Duryea 1984, Ritchie 1984, Duryea 1985), and nurseries and reforestation organizations are examining more closely the use of physiological qualities (e.g., root growth potential, frost hardiness, stress response, or vigor) as well as traditional morphological measurements in assessing field performance potential.

The objective of this study was to investigate the relationships of Douglas-fir (Pseudotsuga menziesii) first-year field performance to nursery measurements of seedling phenology, morphology, and vigor.

MATERIALS AND METHODS

Data for this study were originally gathered during an investigation of top-pruning effects on the morphology, physiology, and field performance of Douglas-fir (Duryea and Omi, unpublished). In 1983, two-year-old bareroot seedlings were selected at six nurseries in central California, Oregon, and southwestern Washington (fig. 1). Four plots (averaging 3.7 x 1.2 m) of unpruned seedlings were selected from each of two seed sources at each nursery. Seed zones ranged in elevation from 305 to 1219 m (table 1). Because one seed source was common to four of the nurseries, nine seed sources were represented in the study. Forty-eight samples were used for comparing seedling characteristics to field performance (12 nursery and seed source combinations x 4 plots).

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MEASUREMENTS

Phenology

Nursery flushing date was defined as the date during the second growing season when 50 percent of the seedlings had initiated growth (needles emerging through bud scales). Approximately six weeks after this date, 20 seedlings per plot were flagged and numbered. The terminal bud of each was rated as growing (flushed) or not actively growing (budset), and was monitored by nursery personnel approximately once a week for 14 weeks and then once every two weeks until late fall. The two phenological measurements derived for each seedling were budset date (Julian date of final budset) and weeks to budset (number of weeks from flushing date to final budset). This second measurement, therefore, assesses growing-season length.

Morphology

Seedlings were lifted during January and February 1984 (table 1) and graded. In contrast to some operational grading procedures, seedlings with multiple leaders were retained if they met all other standards. After grading, seedlings were root-pruned to 25 cm, and approximately 20 seedlings per plot were measured for shoot height, stem diameter, number of branches, terminal bud length, and shoot and root dry weights. Shoot:root ratios were calculated from these dry weights.

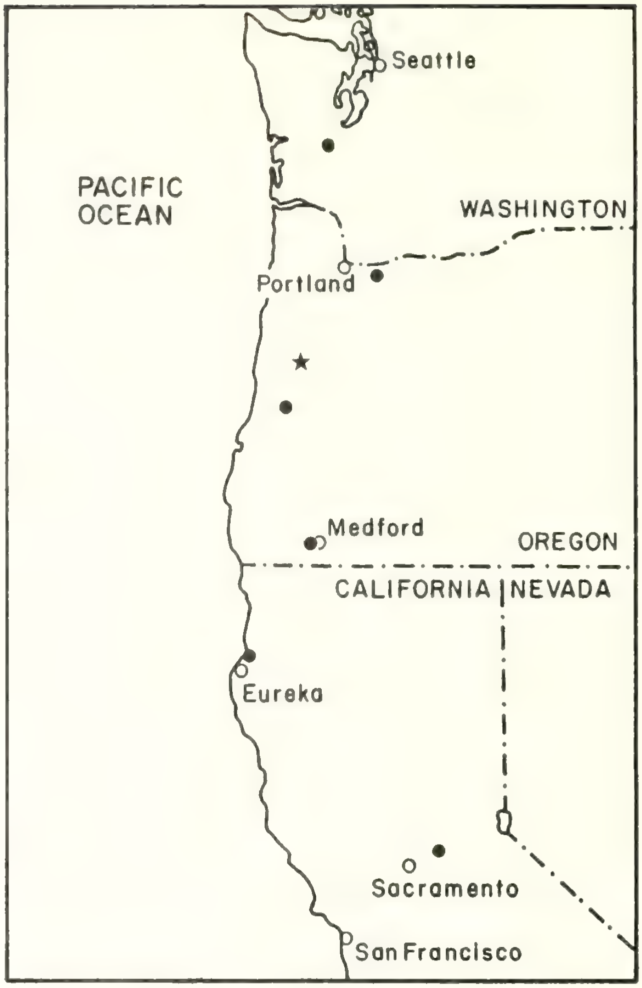

Figure 1. Locations of nurseries (•) and planting site (★).

Table 1. Nursery and seed zone characteristics and lifting and planting dates for the twelve nursery and seed source combinations.

Nursery[1]	Seed zone	Elevation in ft (m)	Owner of stock	Seedbed density in seedlings per ft^2 (m^2)	Lifting date	Planting dates
1	030	1000 (305)	Washington Dept. of	22 (237)	2/7/84	3/14/84 - 3/27/84
	430	1000 (305)	Natural Resources	24 (258)	1/10/84	3/14/84 - 3/27/84
2	270	1500 (457)	International Paper Co.	22 (237)	2/14/84	3/28/84 - 4/11/84
	461	3500 (1067)	Willamette Industries	20 (215)	2/14/84	3/14/84 - 3/27/84
3	270	2000 (610)	Medford District, BLM	30 (323)	1/17/84	3/28/84 - 4/11/84
	062	1500 (457)	Eugene District, BLM	22 (237)	1/17/84	3/14/84 - 3/27/84
4	270	2500 (762)	Medford District, BLM	34 (366)	1/11/84	3/28/84 - 4/11/84
	492	3500 (1067)	Umpqua National Forest	26 (280)	1/11/84	3/14/84 - 3/27/84
5	270	2000 (610)	Medford District, BLM	21 (226)	1/31/84	3/28/84 - 4/11/84
	072	1000 (305)	Coos Bay District, BLM	22 (237)	1/31/84	3/14/84 - 3/27/84
6	525	4000 (1219)	Tahoe National Forest	34 (366)	1/24/84	3/14/84 - 3/27/84
	524	2500 (762)	Plumas National Forest	48 (517)	1/24/84	3/14/84 - 3/27/84

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[1] See figure 1 for nursery locations.

OSU Vigor Test

A separate sample of 20 shippable seedlings per plot was used for seedling quality evaluation in the OSU vigor test (McCreary and Duryea 1985). Seedlings were randomly divided into two groups of 10. One group was given a 15-minute stress treatment (root exposure at 30°C and 30% relative humidity), and the other was left unstressed (McCreary and Duryea 1985). Two-month greenhouse survival and the number of seedlings that had broken bud after one month were recorded for both groups.

Field Performance

Seedlings were planted on one site at the OSU McDonald Forest in Corvallis, Oregon (fig. 1) over a one-month period in spring 1984 (table 1). Seedlings from each nursery sample were planted as two randomly assigned 10-tree row plots at 1.2 x 1.2 m spacing (960 seedlings total). Vexar® tubes were placed over all seedlings immediately after planting.

In the fall of 1984 (one season after planting), survival, total height, 2+0 height, and stem condition (multiple or dominant leader) were recorded for each tree. First-year height growth was determined by subtracting 2+0 height from first-year height.

Data Analyses

Sample means for all field traits were calculated by averaging over the two 10-tree row plots (20 seedlings). Coefficients of simple determination (r^2) were computed on nursery and field means for all samples (N = 48). In addition, a stepwise regression procedure (SAS Institute, Inc. 1985) was used to develop relationships between the independent (i.e., nursery phenology and morphology, OSU vigor test) and dependent (i.e., field performance) variables, and for these a coefficient of multiple determination (R^2) was calculated. To remain in the model, independent variables had to cause a reduction in the sums of squares of the dependent variable at the 0.05 level of significance. Before analysis, all proportions were transformed to arcsine square-root values (Steel and Torrie 1980).

RESULTS

First-year Field Survival

Correlations of all independent variables with first-year field survival were nonsignificant ($P > 0.05$, table 2). Uniformly high survival among all samples made it difficult to detect significant relationships. Mean survival was 90 percent (s.e. = 1%) and ranged from 70 to 100 percent. Because survival varied little among sample means, no adequate regression model could be derived.

First-year Height

First-year height was significantly correlated ($P < 0.01$) with several independent variables (table 2). Coefficients of determination ranged from 0.14 (budbreak of unstressed seedlings) to 0.84 (height at lifting); budset date and weeks to budset were also significantly correlated with first-year height ($r^2 = 0.35$ and 0.64, respectively). Average first-year height was 43 cm (range 29 to 62 cm, s.e. = 1.34 cm).

The best regression equation for predicting first-year height included height at lifting, shoot:root ratio, and weeks to budset, and accounted for 90 percent of the variation in first-year height. However, variation in height at lifting alone could account for 84 percent of the variation in first-year height.

First-year Height Growth

Nine of the 14 independent variables were significantly correlated with first-year height growth (table 2); root weight and stem diameter at lifting had the highest correlations ($r^2 = 0.43$ for both; fig. 2). Again, weeks to budset had a higher correlation ($r^2 = 0.18$, $P < 0.01$) than budset date ($r^2 = 0.02$, $P > 0.05$).

The best regression equation for predicting first-year height growth accounted for 78 percent of the variation and included root weight, stem diameter, survival and budbreak of unstressed seedlings (OSU vigor test), shoot weight, weeks to budset, and frequency of multiple leaders at lifting. Root weight combined with unstressed vigor-test survival and budbreak accounted for 63 percent of this variation; stem diameter in the same combination accounted for 57 percent.

Because weeks to budset only accounted for an additional three percent of the variation in first-year height growth when entered into the model, we deleted this variable to explore the relationships among the others; and, because the remaining variables could be classified as either physiological (OSU vigor test) or morphological, we investigated each class of independent variables separately. When only morphological variables were considered, the best regression equation involved root weight alone and accounted for 43 percent of the variation in height growth. When only physiological traits were analyzed, both budbreak and survival of unstressed seedlings contributed significantly to reducing the sums of squares ($R^2 = 0.32$).

First-year height and height growth were positively correlated ($r^2 = 0.26$, $P < 0.01$). First-year height growth averaged 7 cm (s.e. = 0.3 cm) and ranged from 3 to 12 cm.

Frequency of Multiple Tops After One Year

After one year in the field, only four independent variables were significantly correlated with the proportion of multiple-leader seedlings (table 2); first-year height growth and multiple-leader frequency in the field were negatively related ($r^2 = 0.16$, $P < 0.01$). Mean frequency of seedlings with multiple leaders in the field was 21 percent (s.e. = 2%) and ranged from 0 to 61 percent.

The best predictive regression equation included the proportion of multiple-leader seedlings at lifting, weeks to budset, and height at lifting, and accounted for 46 percent of the observed variation in multiple-leader frequency in the field.

DISCUSSION

Significant correlations between nursery characteristics and field performance suggest that a variety of phenological, morphological, and physiological nursery characteristics could be used for predicting seedling quality for the samples in this study. Several of these relationships previously have been confirmed. Thompson (1985) indicated that morphological characteristics such as seedling height, stem diameter, dry weight, and bud length are significantly correlated with the field performance of many conifer species. McCreary and Duryea (1985) reported significant correlations between the OSU vigor test and field performance.

In our study, morphological variables were consistently the best predictors of field performance. Although the best regression model for predicting first-year height included other variables, height at lifting accounted for 84 percent of the variation. Similarly, combining root weight or stem diameter with OSU vigor test measurements yielded significant regression equations for first-year height growth. However, of the important seedling-quality indicators in this study, stem diameter appeared to be one of the most practical because of its ease of measurement.

Height at lifting was not significantly related to first-year height growth ($r^2 = 0.05$). Because it is reasonable to expect

Table 2. Coefficients of determination (r^2) relating first-year field performance with nursery budset and with morphology and OSU vigor test at lifting.

	First-year field performance			
Nursery variable	Survival (%)	Height (cm)	Height growth (cm)	Multiple leader (%)
Weeks to budset	0.04	0.64**	0.18**	0.01
Morphology at lifting				
Root weight (gm)	0	0.26**	0.43**	0
Shoot weight (gm)	0	0.59**	0.25**	0.02
Total weight (gm)	0	0.50**	0.32**	0
Height (cm)	0.05	0.84**	0.05	0.10*
Stem diameter (mm)	0	0.42**	0.43**	0
Number of branches	0.01	0.21**	0.01	0.06
Terminal bud length (mm)	0.01	0.18**	0.13*	0.04
Shoot:root ratio	0	0.20**	0.08*	0.23**
Multiple leader (%)	0	0.03	0	0.21**
OSU vigor test at lifting				
Unstressed seedlings				
Survival (%)	0.06	0.05	0.10*	0.07
Budbreak (%)	0	0.14**	0.08*	0.02
Stressed seedlings				
Survival (%)	0.01	0.02	0.03	0.19**
Budbreak (%)	0.01	0.08*	0	0.08

* Significant at $P < 0.05$
** Significant at $P < 0.01$

that future growth potential is more closely related to first-year height growth than to height at lifting, the latter seemed relatively unimportant for assessing the field growth potential of seedlings in this study. If superior first-year height growth translates into growth superiority in later years, the seedling traits most important to consider for long-term performance are those which, either alone or in combination, best predict first-year height growth.

Although weeks to budset (length of growing season) was correlated with first year height ($r^2 = 0.64$) and height growth ($r^2 = 0.18$), it may not be useful as an indicator of seedling quality because of the time required for measurement. In addition, when combined with the other independent variables in the best models, weeks to budset only accounted for 2 to 3 percent of the variation in first-year height and height growth. However, weeks to budset was consistently a better predictor of field performance than budset date, probably because budset date is strongly influenced by the nursery environment. The nurseries in this study were geographically distant; seedlings in nurseries farther north would naturally have earlier budset dates because of climate and cultural practices that induce earlier seedling dormancy. Weeks to budset is less influenced by differences in nursery environment because it is essentially a measure of growing season length, and, although growing season length also varies somewhat among nurseries, the predictive ability of this variable appeared to be better than that of budset date.

As with phenological characteristics, OSU vigor test variables require more time for measurement than do morphological characteristics; and, in contrast to previous reports (McCreary and Duryea 1985), we found poor relationships between OSU vigor test variables and field performance. This may be due to confounding effects of planting dates and storage intervals for the twelve nursery and seed source combinations; the time interval between stress tests and actual planting date must be minimized (McCreary and Duryea 1985), and that interval ranged from one to three months in this study. Another possible explanation is the lack of variability in vigor-test means. For example, average growth-room survival of unstressed seedlings was consist-

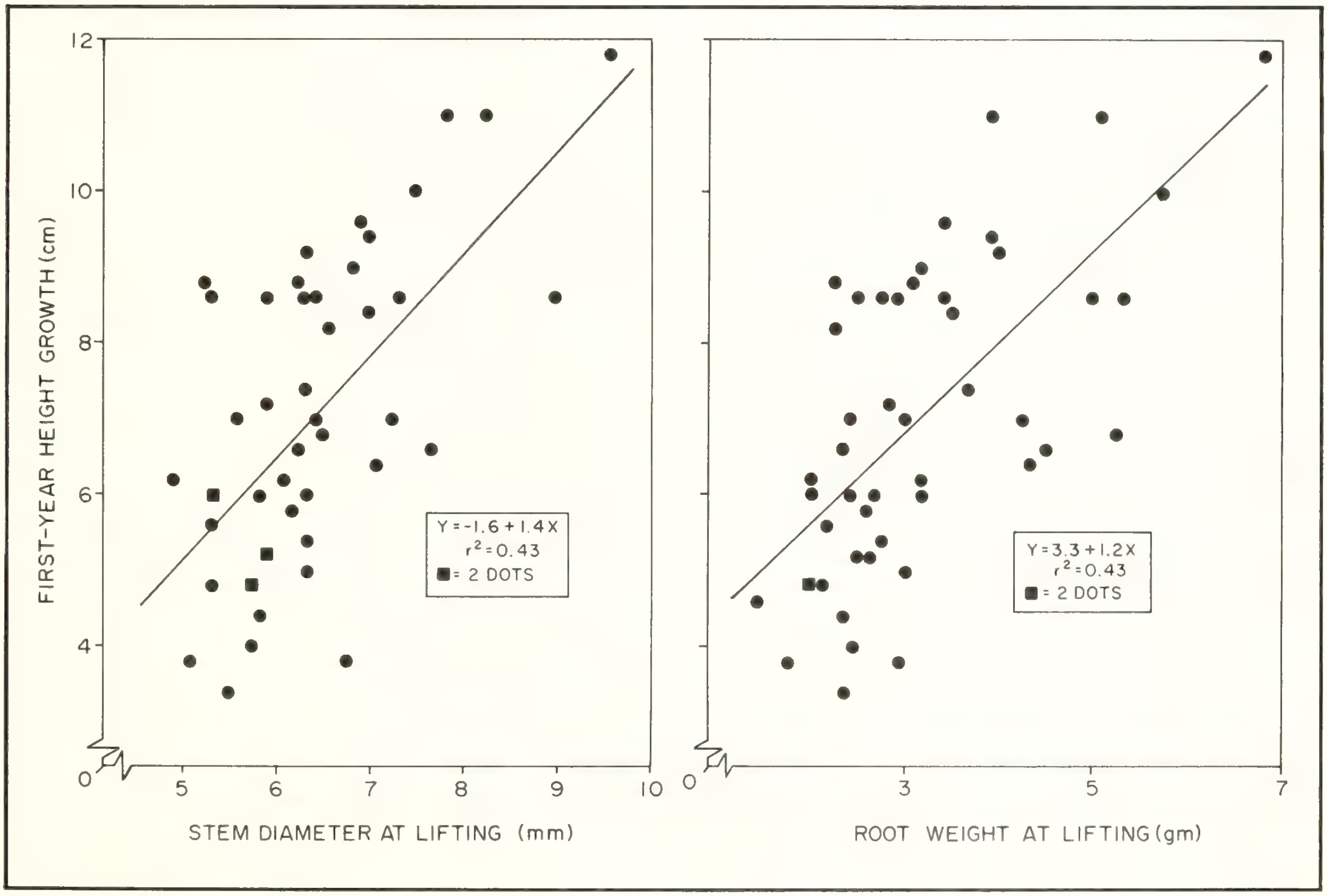

Figure 2. Relationship of first-year height growth to stem diameter and root weight at lifting.

ently high (average 97%, range 50 to 100%), which made it difficult to develop strong relationships with the dependent variables (McCreary and Duryea 1985).

The significance of multiple leaders as an indicator of seedling quality is largely unknown. Reports in the literature suggest that apical dominance is apparent in multiple-leader seedlings after two growing seasons in the field (Lanquist 1966, Dierauf 1976, Webb and Reese 1984). Three years after outplanting, survival of white spruce (Picea glauca), black spruce (Picea mariana), and jack pine (Pinus banksiana) differed little between trees with single leaders and those with multiple leaders at lifting (Webb and Reese 1984). Webb and Reese (1984) also indicated that multiple-leader trees may have field height growth similar to that of single-leader trees. In our study, the nursery multiple-leader condition was positively correlated, and first-year height growth was negatively correlated, with the occurrence of multiple leaders after the first growing season in the field. The long-term retention of multiple leaders and its effect on field performance remain to be investigated.

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Winter Sowing for Production of 1-0 Douglas-fir Planting Stock[1]

James L. Jenkinson and James A. Nelson [2]

Abstract.--Effects of early sowing on emergence and growth of Douglas-fir were examined in the Humboldt Nursery on California's north coast. In a 1979 study, seeds from coastal and inland regions of western Oregon and northern California were chilled 30 or 90 days at 1°C and sown in March and May. Chilling seeds for 90 days resulted in greater speed and amount of seedling emergence in cool soil (March) and greater speed of emergence in warm soil (May). March sowing captured at least six additional weeks early in the potential growing season and resulted in 1-0 seedlings that were large enough to outplant. Top dry weight was increased by 63 to 106 percent and root dry weight after pruning, by 24 to 82 percent, depending on seed source. In a 1985 study, seeds of coastal and inland sources were chilled 90 days and sown in January, February, March, April, and May. Sizes of the resulting 1-0 seedlings defined sowing windows that were wide open in February and closed in late April. Relative stem volumes in the February through May sowings were 7.5, 4.2, 2.9, and 1.0, and the cull percentages, 14, 21, 38, and 82, respectively. Humboldt Nursery can efficiently produce 1-0 Douglas-fir for the Pacific slope by sowing fully chilled seeds in winter and early spring.

INTRODUCTION

Planting 1-0 seedlings of Pacific Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco) is an attractive option for reforestation programs in the Pacific slope regions of western Oregon and northern California. Advantages for forest management include shorter lead times and greater silvicultural flexibility for regenerating harvested stands and forests burned by wildfire. Advantages for nursery management include more frequent cover cropping or fallow years and ripping or chisel plowing to improve soil aeration and drainage. Compared with 2-0 seedlings, 1-0 seedlings take less water, fertilizer, weeding, and inventory effort, require neither undercutting nor vertical pruning of roots in the nursery, and cost less to lift, grade, pack, store, ship, and plant. They are more easily lifted and separated without mechanical damage to the roots, and standard root pruning removes less of the lifted root system. Up to three times as many 1-0 as 2-0 seedlings can fit in the standard packing bag, tripling the capacity of premium cold storage. Because 1-0 seedlings are easier to plant with proper root placement and easier to protect against depredation by animals, their use may enhance early plantation establishment.

The biological basis for growing 1-0 Douglas-fir partly rests on knowledge of the physiological ecology of conifer seeds and seedlings. Seeds of most conifers in the wild, including those of Douglas-fir on the Pacific slope, are shed in autumn, undergo moist overwinter chilling, and germinate in early spring. Research on Douglas-fir, sugar pine (Pinus lambertiana Dougl.), ponderosa pine (P. ponderosa Dougl. ex Laws.), loblolly pine (P. taeda L.), lodgepole pine (P. contorta Dougl.), Engelmann spruce (Picea engelmannii [Parry]

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Engelm.), and Fraser fir (Abies fraseri [Pursh] Poir.) has shown that prolonged chilling may enable rapid germination, seedling emergence, and early growth in cool conditions (Adkins and others 1984, Allen 1960, Danielson and Tanaka 1978, Dunlap and Barnett 1982, Jenkinson and others 1982, McLemore 1969, Sorensen 1978, Tanaka and others 1986). Moreover, cool soils may restrict the lethal activity of damping-off and Fusarium root disease (Bloomberg 1973, Filer and Peterson 1975, Jenkinson and others 1982, Smith 1975) and promote the early mycorrhizal development and protection of young seedling roots (Parke and others 1983, Sinclair 1974, Sinclair and others 1982, Sylvia 1983).

Nursery and field experience with three widespread pines in California encouraged our work on Douglas-fir. By sowing in May, nurseries in the western Sierra Nevada readily produce successful 1-0 seedlings of ponderosa and Jeffrey pines (Pinus jeffreyi Grev. & Balf.) for many different seed sources (Jenkinson 1980). In these same nurseries, the traditional May sowings always take 2 years to grow acceptable crops of sugar pine. A recent April sowing of sugar pine at the Placerville Nursery nevertheless produced successful 1-0 seedlings for a number of different seed sources in the North Coast Range and Sierra Nevada (U.S. Dep. Agric., Forest Service 1982). In the nearby Institute of Forest Genetics nursery, February and March sowings of sugar pine from an elevational transect of the western Sierra consistently produced large and healthy 1-0 seedlings, whereas seedlings in May sowings were highly susceptible to Fusarium disease and too small to outplant (Jenkinson and others 1982).

Situated on the Pacific Coast near McKinleyville, the Humboldt Nursery is historically free of winter snow and frozen soil, but traditionally has sown in May to avoid the rainy season. Seedlings of all conifers in these late spring sowings require 2 years to reach acceptable planting sizes. By contrast, trial sowings of Douglas-fir in March and April have commonly produced 1-0 seedlings that were big enough to outplant. No other treatment was needed.

To evaluate the survival and growth potential of its 1-0 Douglas-fir, Humboldt Nursery and its clientele established a series of field tests in the Oregon Coast and Cascade Ranges, the Klamath Mountains, and the North Coast Range of California. Seedlings were planted in spring on cleared sites in the seed zone of origin for a total of 11 different seed sources. Results were encouraging. For seedlings dug within the seed source lifting window (Jenkinson and Nelson 1978), field survival averaged 81 to 99 percent, depending on planting site, and tree heights often doubled in the first and second years (Jenkinson 1984; Jenkinson and Nelson 1983, 1985; Turpin and others 1985).

It seems evident that by sowing early, bareroot nurseries in California might easily produce 1-0 planting stock for sugar pine and Douglas-fir. Yet responsible nursery people hesitate to shift from the traditional sowing schedules, and for valid reasons (Owston and Stein 1974). Seed treatment and soil preparations for early sowing will necessarily invade the nursery lifting season, and the usual winter and spring rains will typically obstruct any calendar for seedling harvest, nursery bed formation, and early sowing. In such circumstances, work plans must be highly flexible if harvest and sowing schedules are to be coordinated effectively. The greatest deterrent to sowing early is the occasional torrential rain that can cause severe soil erosion, destroy newly sown beds, and force another sowing with summer imminent.

This paper reports two studies of early sowing in the Humboldt Nursery and offers guides for the production of large, 1-0 planting stock for Pacific Douglas-fir. In 1979, we explored the effects of seed chilling period and nursery sowing date on the speed and amount of seed germination, seedling emergence and growth for seed sources from coastal and inland regions of western Oregon and northern California. Seedlings from this study were successfully tested for field survival and growth (Jenkinson and Nelson 1983). In 1985, we investigated the nursery sowing windows--that is, the earliest and latest safe times to sow coastal and inland seed sources for the production of 1-0 stock--and explored ways to control erosion in the seed beds. Field tests of seedlings from this study are in progress.

MATERIALS AND METHODS

For the 1979 study, seed sources were chosen in the Oregon Coast Range and western Cascade Range, and in the North Coast Range and eastern Klamath Mountains of California (table 1). These sources represent the diversity of coastal and inland regions supplied with planting stock from Humboldt Nursery.

Seed Germination Test

Seeds were soaked 36 hours in aerated water at 22°C (72°F), chilled 0, 20, 40, or 60 days at 1°C (34°F) to bracket Humboldt's traditional 30 days, and germinated at 22°C on moist filter paper in 11-cm Petri dishes. Each dish contained 100 seeds of a particular source and chilling treatment, and each combination was replicated four times. Filter papers were kept moist with a dilute suspension of captan fungicide. Germinated seeds were counted and removed at 7, 14, and 21 days. A seed was considered germinated once the radicle had extended 2 mm beyond the seedcoat and showed positive geotropic response.

The effects of seed source and chilling period on germination were assessed by analysis of variance using BMD P2V (Jennrich and others 1981).

Table 1. Seed sources used to investigate early spring and winter sowing for the production of 1-0 Douglas-fir at Humboldt Nursery

Forest region and seed source code	Ranger District or Resource Unit	Tree seed zone [2]	Seed parent elevations (ft)[3]
March and May sowings, 1979			
Oregon Coast Range AL 252.15	Alsea	252	1000-1500
Cascade Range, western MK 472.30	McKenzie	472	2500-3000
North Coast Range KR 390.20	King Range [1]	390	1500-2000
Klamath Mtns, eastern OK 321.30	Oak Knoll	321	2500-3000
January through May sowings, 1985			
North Coast Range GQ 091.25	Gasquet	091	2000-2500
Klamath Mtns, central SA 311.40	Salmon River	311	3500-4000

[1] Bureau of Land Management.

[2] U.S. Dep. of Agric., Forest Service 1969, 1973.

[3] 1 m = 3.28 ft.

Seedling Emergence and Growth Test

Seeds were soaked 36 hours in aerated water at 22°C, chilled 30 or 90 days at 1°C, and sown in the nursery on March 14 and May 15. Adjacent beds were prepared by the standard chisel plow and power harrow method in early March. Monoammonium phosphate (11-48-0) and potassium sulfate (0-0-52) were incorporated into the soil during bed preparation, according to traditional practice (200 lb and 50 lb material/acre, respectively). To facilitate plot installation and cultural treatments, one bed was necessarily assigned the March sowing and the other, the May sowing. A Love-Oyjord seeder was used to sow the seeds at a depth of 3 to 6 mm and in the standard 8-row pattern, to provide 30 seedlings per square foot (325 per m^2).

The design of the test consisted of five replications of a randomized complete block of split plots. The bed pair was divided into five blocks of seed source plots. The blocks were 80 ft long, the source plots, 20 ft, and the treatment plots, 10 ft (1 ft = 30.5 cm). The source plots were split across the beds for chilling treatment and between the beds for sowing dates. The five replications extended 400 ft, sampling most of the width of the nursery block or soil management unit.

Water was applied by impact sprinklers, as needed to moisten the soil surface during emergence, and once or twice weekly to irrigate the soil profile through the growing season. The seedlings were not fertilized.

To track seedling emergence, four sample plots were randomly located in seed rows 2 to 7 of the middle 5 ft of each chilling treatment plot. Each sample plot consisted of 1 ft of seed row and was permanently marked with parallin stakes. New germinants were counted three times weekly after emergence began, and less frequently as emergence neared completion. A germinant was counted after its hypocotyl penetrated the bed surface.

In December, seedlings were dug from the sample plots, combined by treatment plot, carefully washed free of soil, root-pruned 23 cm (9 in) below the cotyledon node, and graded to eliminate any damaged individuals. Ten randomly selected seedlings per treatment plot were evaluated for shoot height above the cotyledon node, stem diameter 1 cm below the node, and oven dry weights (65°C or 140°F) of the top and roots separated at the node.

The effects of seed source and chilling period on seedling emergence were assessed for the March and May sowings separately, by analysis of variance BMD P8V (Jennrich and Sampson 1981). The data were analyzed as a split plot design, with seed sources and chilling periods considered fixed and the blocks, random.

The effects of seed source, chilling period, and sowing date on seedling growth were also assessed by BMD P8V. The data were analyzed as a split-split plot design with seed sources, chilling periods, and sowing dates considered fixed and the blocks, random.

Determining Nursery Sowing Windows

For the 1985 study, seed sources representing coastal and inland regions were chosen in the North Coast Range and the central Klamath Mountains of California (table 1).

Seeds were soaked 24 hours in aerated water at 22°C, chilled 90 days at 1°C, and sown in the nursery on January 15, February 19, March 21, April 23, and May 17. One full bed was prepared by the chisel plow and power harrow method in early January, when soil conditions were favorable. Triple super phosphate (0-48-0) and potassium sulfate (0-0-52) were incorporated into the soil during bed preparation (440 lb and 200 lb material/acre, respectively). The shaped bed was protected against erosion by covering the soil surface with a 1/4-inch-mesh net made of polypropylene. The net was removed as the plots were sown. A Love-Oyjord seeder again was used to sow the seeds at a depth of 3 to 6 mm and in the standard 8-row pattern, to provide 30 seedlings per square foot (325 per m^2).

The design of the test consisted of three replications of a randomized complete block of split plots. Sowing date was split for seed source and seed source was split for a check and three erosion control methods, that is, a woven tissue paper mat, hydromulch (Landis and others 1984), and a 30-percent shade polypropylene cloth stretched 20 cm (8 in) above the soil surface. The sowing-date plots were 40 ft long, the source plots, 20 ft, and the treatment plots, 5 ft (1 ft = 30.5 cm). The three replications extended 600 ft, sampling the full width of the nursery block or soil management unit.

Water was applied by impact sprinklers, as needed to keep the soil surface moist during emergence and twice a week to irrigate the soil profile as seedlings grew and summer progressed. Seedlings of each sowing were fertilized with nitrogen within 2 months of emergence (100 lb N/acre). The soil surface was scarified between seedling rows and top-dressed with granular ammonium phosphate sulfate (NPS 16-20-13, 625 lb material/acre). Time of application varied with the sowing date, which largely determined time of emergence.

Initial emergence was recorded for each sowing. Seedling height was measured in July, August, September, and October, and stem diameter, in October. A standard nursery inventory frame (0.5 by 4 ft or 15 x 122 cm long) was set across the bed in each of two randomly located positions per plot. Seedlings within the frame were counted and measured separately for rows 1 to 4 and 5 to 8.

Effects of seed source, sowing date, and erosion control on seedling growth and stocking were assessed by analysis of variance BMD P8V (Jennrich and Sampson 1981). The data were analyzed as a split-split plot design with seed sources, sowing dates, and erosion control considered fixed and the blocks, random.

For each source, coefficients of determination were calculated to assess the relations of seedling height and stem volume to sowing date and time of emergence (Ryan and others 1981). The frequency distributions of stem diameter were determined for each sowing, using BMD P5D (Chasen 1981).

RESULTS

Seed sources from both coastal and inland regions required prolonged chilling and early sowing to produce 1-0 seedlings efficiently.

Seed Chilling and Germination

In the 1979 study, germination was significantly affected by seed source and chilling period (0, 20, 40, or 60 days) and their interaction after 7, 14, and 21 days at room temperature (table 2).

Both the speed and amount of germination were greatest with 60 days of chilling for three of the four sources tested (fig. 1, table 3). The 20-day chill sacrificed speed in every source and enabled complete germination of only the North Coast, or King Range, source. After 7 days, germination was highest with the 60-day chill for sources from the Oregon Coast Range (AL), Cascade Range (MK), and Klamath Mountains (OK), and with the 40- and 60-day chills for the King Range (KR). After 21 days, germination was highest with the 60-day chill for source MK, nearly as high with the 40- as the 60-day chill for sources AL and OK, and about equally high with the 20-, 40-, and 60-day chills for source KR.

Seedling Emergence in March and May Sowings

Emergence was significantly affected by the seed source and chilling period (30 versus 90

Table 2. Significance of effects of seed source and chilling period on the cumulative germination of Douglas-fir seeds [1]

Source of variation	Degrees freedom	Variance (mean square) for germination (percent), by day		
		7	14	21
Seed source, S	3	1453.9**	491.2**	380.1**
Chilling period, T	3	19444.1**	21978.9**	15367.6**
ST	9	529.8**	433.3**	469.4**
Error	48	37.8	28.9	29.8

[1] Seeds from coastal and inland regions in Oregon and California were chilled for 0, 20, 40, or 60 days.

** Statistically significant at the 1 percent level.

days) in both the March and May sowings, and by their interaction in the March sowing (table 4).

For the March sowing, emergence began on March 29, 15 days after sowing, and was essentially completed by May 7, 54 days after sowing (fig. 2, table 5). The 90-day chill resulted in faster and greater emergence than did the 30-day chill. At 28 days, emergence for the 90-day chill was greater by factors of 4.3, 2.0, 1.4, and 1.7 in sources AL, MK, KR, and OK, respectively. The 90-day chill, compared to the 30-day, increased total emergence by an absolute 46 percent in source AL, 16 percent in source MK, and 29 percent in source OK.

For the May sowing, emergence began on May 25, 10 days after sowing, and was finished by June 14, 30 days after sowing. The 90-day chill again resulted in faster emergence but did not increase total emergence. At 15 days, emergence for the 90-day chill exceeded that for the 30-day by factors of 4.2, 1.8, 1.6, and 1.4 in sources AL, MK, KR, and OK, respectively.

Seedling Growth in March and May Sowings

Sowing date significantly affected seedling height, stem diameter, top dry weight and root dry weight after pruning, but not top/root ratio (table 6). The seed source significantly affected seedling height, stem diameter, top weight and top/root ratio, but not root weight. The chilling period significantly affected seedling height, but no other size trait.

Seedling height and top dry weight decreased with increase in source latitude and distance inland from the Pacific Coast (table 7). The coastal sources, Al and KR, were taller than their inland counterparts, MK and OK, and the California

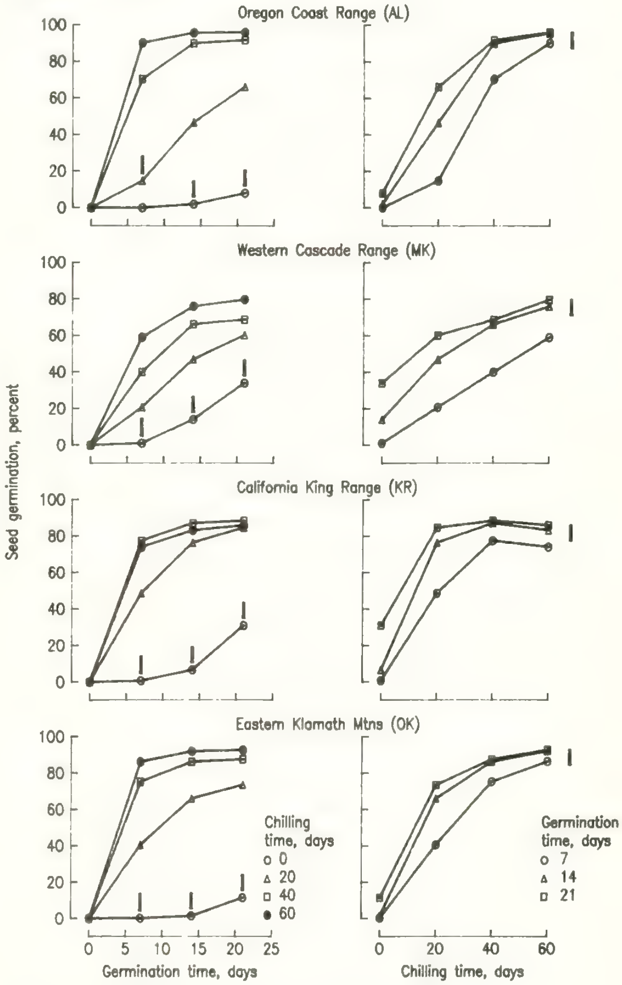

Figure 1. Seed source and chilling period significantly affected germination of Douglas-fir seed. Curves are for chilling periods of 0, 20, 40, and 60 days at 1°C (left panel) and germination periods of 7, 14, and 21 days at 22°C (right panel). Bars indicate least significant difference at the 5 percent level.

Table 3. Effects of seed source and chilling period on the cumulative germination of Douglas-fir seeds

Seed source and germination time (days)	Germination (percent), by chilling period (days)[1]				LSD[2]
	0	20	40	60	
Oregon Coast Range (AL)					
7	0.0	14.7	70.5	90.2	8.8
14	2.0	46.7	90.0	95.7	7.7
21	8.0	66.2	91.7	96.0	7.8
Cascade Range, western (MK)					
7	1.0	20.7	40.0	59.0	8.8
14	14.0	47.0	66.2	76.0	7.7
21	34.0	60.2	68.7	79.7	7.8
North Coast Range (KR)					
7	0.7	48.7	77.5	74.0	8.8
14	6.7	76.5	87.2	83.2	7.7
21	31.0	84.7	88.5	86.0	7.8
Klamath Mtns, eastern (OK)					
7	0.2	40.5	75.2	86.2	8.8
14	1.5	66.0	86.2	92.0	7.7
21	11.5	73.5	87.5	92.7	7.8

[1] Values are the means of four replications of 100 seeds each.

[2] Least significant difference at the 5 percent level.

Table 4. Significance of effects of seed source and chilling period on seedling emergence in March and May sowings of Douglas-fir in Humboldt Nursery (1979) [1]

Source of variation	Error term	Degrees freedom	Variance (mean square) for emergence (percent)					
			March sowing, by day			May sowing, by day		
			28	37	44	15	21	28
Seed source, S	SB	3	250.8**	142.5	102.3	1391.6**	1867.8**	1729.3**
Chilling period, T	TB	1	1452.0**	1404.2*	1113.0*	1322.5**	1081.6**	483.0*
Block, B	[2]	4	68.6	28.9	34.6	101.1	297.5	182.9
ST	STB	3	58.1	156.2*	158.3*	118.5	126.5	230.6
SB	STB	12	39.3	82.5	76.3	41.5	107.6	104.9
TB	STB	4	54.7	124.9*	138.2*	29.6	9.0	39.2
STB		12	29.1	37.8	40.8	55.6	120.3	210.1

[1] Seeds from coastal and inland regions in Oregon and California were chilled for 30 or 90 days.

[2] SB + TB - STB for March dates; STB for May dates. F-Tests with the Satterthwaite approximation using only the variance components with positive method of moments estimates.

*, ** Statistically significant at the 5, 1 percent levels.

sources, KR and OK, were taller than their Oregon counterparts, AL and MK.

Seedlings from the March sowing were taller and stouter and had greater top and root dry weights than seedlings from the May sowing (fig. 3). Seedlings of sources AL, MK, KR, and OK were respectively 21, 27, 24, and 35 percent taller and had 26, 31, 31, and 44 percent greater stem diameter. They had 63, 68, 92, and 106 percent greater top weight, and 24, 45, 82, and 61 percent more root weight. Increases in top/root ratio were not significant.

Nursery Sowing Windows

In the 1985 study, several problems related to sowing time and seedling emergence required solution. The January sowing was necessarily dropped from the analyses because a flock of juncos partially harvested the plots soon after emergence began. Depredation of the February and later sowings was forestalled by spraying the newly sown plots with a bird repellant containing the fungicide thiram.

The nursery soil was crusted by February and needed scarification to shatter the crust and enable a uniform sowing depth and density. Thus the February, March, April, and May sowings were done after first raking the plots with steel tines.

The woven paper mat treatment was discontinued after it badly entangled emerging seedlings in the February sowing. In every sowing, the shade cloth in the shade cloth treatment was permanently removed after emergence was well underway, to permit drying of the soil surface to inhibit damping-off disease.

Seedling height, stem diameter, and stocking in October were significantly affected by sowing date and replication (table 8). In addition, seedling stocking was significantly affected by seed source and erosion control. All traits were significantly affected by various interactions. Results of the analyses of seedling height and stocking in July, August, and September (not presented) were mostly like those in October, at the close of the growing season.

Seedling Growth.--Throughout the growing season, seedlings of both the coastal and inland seed sources were consistently taller with earlier sowing (table 9). At the end of the growing season, stem height and diameter for the coastal seedlings were 106 and 82 percent greater in the February than in the May sowing, and for the inland seedlings, 115 and 95 percent greater.

In July, the inland seedlings were taller than the coastal seedlings and they remained so through August for all sowing dates. In September, inland seedlings were still slightly taller in the March, April, and May sowings, but coastal seedlings were

Table 5. Effects of seed source and chilling period on seedling emergence in March and May sowings of Douglas-fir in Humboldt Nursery (1979) [1]

Seed source and chilling period (days)	Emergence (percent)															
	March sowing, by day								May sowing, by day							
	21	23	26	28	30	37	44	54	11	15	17	21	23	25	28	30
Oregon Coast Range (AL)																
30	1.9	2.8	6.9	13.0	24.1	37.5	49.1	53.7	0.0	6.3	16.8	70.2	82.1	89.5	98.6	100.0
90	4.6	14.8	33.3	56.5	69.0	88.4	95.8	100.0	0.0	26.4	46.8	85.6	90.8	93.3	97.9	100.0
Cascade Range, western (MK)																
30	6.4	9.6	28.8	30.4	43.3	64.1	76.3	84.0	0.0	8.7	25.5	66.4	80.5	88.6	96.0	100.0
90	12.2	21.8	38.5	59.6	75.0	91.7	97.4	100.0	0.0	16.1	35.5	73.7	79.6	88.2	98.4	100.0
North Coast Range (KR)																
30	13.0	21.2	43.5	56.5	67.4	89.7	97.8	100.0	0.7	31.7	53.0	82.2	90.7	92.2	98.6	100.0
90	20.0	33.7	60.0	77.7	83.4	97.7	99.4	100.0	3.0	51.1	70.2	89.8	93.8	96.0	98.4	100.0
Klamath Mtns, eastern (OK)																
30	13.6	23.8	30.2	42.6	49.0	60.9	66.3	70.8	0.8	41.5	63.1	86.4	91.9	95.8	98.3	100.0
90	28.2	44.6	62.4	72.8	82.2	94.1	99.5	100.0	9.5	57.3	69.7	91.2	93.8	96.7	98.5	100.0

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[1] Values are expressed as percent of maximum for the seed source.

taller in the February sowing. In October, coastal seedlings were taller and stouter than inland seedlings, regardless of the sowing date (table 9).

For seedlings of both sources, the seasonal pattern of height growth varied with sowing date (fig. 4). Through September, growth rates were higher in the February than in the May sowing. From September to October, growth rates decreased in the February sowing and increased in the May sowing. Intermediate patterns were found in the intervening March and April sowings.

Seedling Stocking.--Seedling stocking decreased with earlier sowing and the rate of reduction was greater for the coastal than for the inland seed source (fig. 5, table 9). Averaged over all sample dates, stocking for coastal seedlings in the February, March, and April sowings was 63, 71, and 87 percent of that in the May sowing, and for inland seedlings, 83, 89, and 92 percent. These differential trends in stocking explain the highly significant interaction of seed source and sowing date (table 8).

Erosion Control.--Use of hydromulch and shade cloth improved stocking for seedlings of the coastal but not inland seed source (table 10). Stocking for coastal seedlings in the hydromulch and shade cloth plots respectively was 24 and 41 percent greater than in the check plots, and for inland seedlings, zero and 5 percent. The interaction of seed source and erosion control was significant in the inventories for July and August, but not September and October.

Humboldt Nursery received an average number of heavy rainstorms in the January-March period of 1985 (fig. 6). Each of four storms delivered 2 inches (5.1 cm) or more within 48 hours. The January sowing got all of these rains and the February and March sowings, two of them. The seed beds were saturated each time, but there was no visible evidence of soil erosion nor of any washing of seed or germinants, even in the check plots.

DISCUSSION

Whatever the seed source, the size of 1-0 seedlings in Humboldt Nursery largely depends on how early the seed is sown. Sowing early captures valuable weeks and months at the front end of the growing season, even though the prevailing cool soil conditions slow germination and prolong emergence. In 1979 at Humboldt, the usual cool soil of early spring stretched emergence of the March sowing to the first of May, and the typically warm soil of late spring enabled complete emergence of the May sowing by the middle of June. But by the time emergence was complete in the May sowing, most seedlings in the March sowing had been elongating roots and expanding shoots for more than 6 weeks.

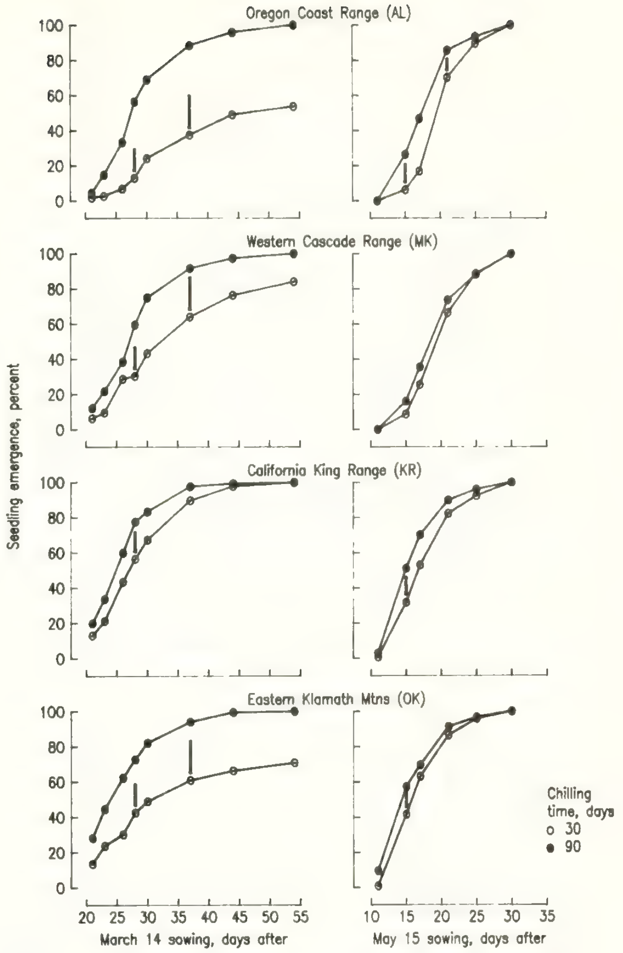

Figure 2. Seed source, chilling period, and sowing date markedly affected emergence of Douglas-fir in Humboldt Nursery. Curves are for chilling periods of 30 and 90 days for sowings on March 14 (left panel) and May 15 (right panel). Bars indicate least significant difference at the 5 percent level.

Similar patterns of emergence and growth held at Humboldt in 1985. Emergence of the January sowing started in the middle of February and emergence of the February sowing was just underway when the March sowing was installed. Germinants in the March, April, and May sowings began to emerge within 18, 9, and 6 days of seeding, respectively. By early April, all seedlings in the January sowing were expanding shoots, and all seedlings in the February sowing had shed their seedcoats. The winter sowings were clearly up and growing more than 3 weeks before emergence began in the April sowing and 6 weeks before it began in the May sowing.

Emergence and Growth in Cool Conditions

Full benefit of early sowing can only be achieved by a seed treatment that effectively substitutes for overwinter chilling in the wild. To insure maximum rates and amounts of emergence in the cool soils that prevail in winter and early

Table 6. Significance of effects of seed source, chilling period, and sowing date on the growth of 1-0 Douglas-fir in Humboldt Nursery (1979) [1]

Source of variation	Error term	Degrees freedom	Variance (mean square) for... Seedling height (cm)	Stem diam (mm)	Top weight (g)	Root weight (g)	Top/root ratio
Sowing date, D	DB	1	235.709**	12.8480**	13.0411**	3.2321**	0.4961
Seed source, S	SB	3	104.367**	2.9942*	1.7454**	.0401	1.9338**
Chilling period, T	TB	1	8.179*	.0130	.1280	.0054	.0858
Block, B	[2]	4	3.232	.0615	.1104	.0352	.2488
DS	DSB	3	2.412	.1224	.3370	.1141	.0801
DT	DTB	1	2.513	.0106	.0442	.0353	.1514
ST	STB	3	1.704	.1178	.1639	.0369	.0307
DB	[3]	4	.652	.2568	.1375	.0252	.1197
SB	[4]	12	4.025	.5519	.1177	.0611	.1089
TB	[5]	4	.816	.0782	.0244	.0308	.0389
DST	DSTB	3	1.438	.0971	.0580	.0389	.0126
DSB	DSTB	12	5.126	.1609	.1440	.0463	.0688
DTB	DSTB	4	1.177	.1809	.0220	.0626	.0827
STB	DSTB	12	2.505	.0757	.0733	.0163	.0607
DSTB		12	1.368	.0852	.0976	.0458	.0243

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[1] Seeds from coastal and inland regions in Oregon and California were chilled for 30 or 90 days and sown in March and May.

[2] DB + SB + TB - DSB - DTB - STB + DSTB (See table 6A for denominators

[3] DSB + DTB - DSTB. [4] DSB + STB - DSTB. [5] DTB + STB - DSTB.

*, ** Statistically significant at the 5, 1 percent levels.

Table 6A. Denominators for F-Tests for Table 6.[1]

Source of variation	Seedling height	Stem diam	Top weight	Root weight	Top/root ratio
B	DSB+STB-DSTB	DB+SB-DSB	DSB	SB+DTB-DSTB	SB+DTB-DSTB
DB	DSB	DTB+DSB-DSTB	DSB	DTB+DSB-DSTB	DTB+DSB-DSTB
SB	DSB+STB-DSTB	DSB	DSB	DSB	DSB+Stb-DSTB
TB	STB	DTB	DSTB	DTB	DTB+STB-DSTB

[1] F-tests with the Satterthwaite approximation using only the variance components with positive method of moments estimated

Table 7. Effects of seed source and sowing date on the growth of 1-0 Douglas-fir in Humboldt Nursery (1979)

Seed source and sowing date [1]	Seedling height (cm)	Stem diam (mm)	Top weight (g)	Root weight (g)	Top/root ratio
Oregon Coast Range (AL)					
March 14	16.0	2.82	1.58	1.14	1.44
May 15	13.2	2.24	0.97	0.92	1.13
Cascade Range, western (MK)					
March 14	13.6	3.36	1.48	1.19	1.27
May 15	10.7	2.57	0.88	0.82	1.16
North Coast Range (KR)					
March 14	19.5	3.80	2.40	1.29	1.91
May 15	15.7	2.89	1.25	0.71	1.90
Klamath Mtns, eastern (OK)					
March 14	16.2	3.02	1.69	1.14	1.51
May 15	12.0	2.09	0.82	0.71	1.31

[1] Within source, values of all traits except top/root ratio were significantly greater for the March sowing. See table 6.

spring, stored seeds must be properly soaked and then chilled for at least 60 and preferably 90 days before sowing. Sources like those from the Oregon Coast Range, Cascade Range, and Klamath Mountains (AL, MK, OK), which typify much of the Pacific slope forests of Douglas-fir in Oregon and California, will require 60 to 90 days of chilling for most rapid and complete germination and emergence (fig. 1, 2). Although certain sources like that of California's north coast King Range (KR) may germinate completely with a 20-day chill and show maximum emergence with a 30-day chill, they will germinate and emerge most rapidly with prolonged chilling.

Early growth in cool conditions may be just as essential for the health of 1-0 Douglas-fir as it is for 1-0 sugar pine (Jenkinson and others 1982). For coastal and inland seed sources, seedlings in our February, March, and April sowings mostly escaped disease, had abundant mycorrhizae and associated mycelium (Laccaria laccata and Thelephora terrestris are common in Humboldt Nursery), and grew uniformly. By contrast, seedlings in our May sowings had incipient problems with Fusarium or other damping-off fungi (Kliejunas and Allison 1982) and exhibited stunting in the classic mosaic pattern

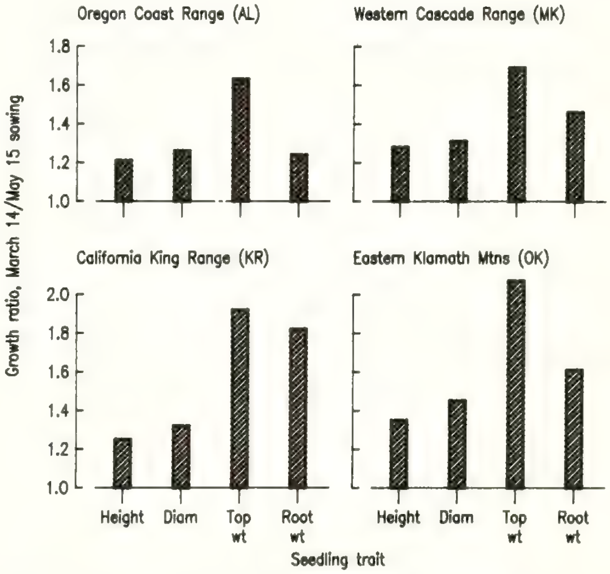

Figure 3. Sowing in early spring compared to late spring resulted in substantial gains in the size and dry weight of 1-0 Douglas-fir in Humboldt Nursery.

Table 8. Significance of effects of seed source, sowing date, and soil erosion control on the growth and stocking of 1-0 Douglas-fir in Humboldt Nursery (1985) [1]

Source of variation	Error term	Degrees freedom	Variance (mean square) for		
			Seedling height (cm)	Stem diam (mm)	Seedlings per ft^2
Sowing date, D	DB	3	1511.28**	32.670**	741.1**
Seed source, S	SB	1	349.80	2.000	803.3*
Erosion control, T	TB	2	1.58	.241	759.8*
Block, B	P	2	262.50**	7.094**	176.3*
DS	DSB	3	5.28	.058	185.1**
DT	DTB	6	26.91**	.097	199.9
ST	STB	2	31.72	.029	149.0
DB	P	6	9.27*	.152	72.9
SB	P	2	37.74**	1.214**	12.9
TB	P	4	34.87**	.731**	62.5
DST	DSTB	6	13.17*	.862*	179.8
DSB	P	6	18.77**	.207	15.7
DTB	P	12	5.26	.230	142.0**
STB	P	4	10.78*	.233	132.6*
DSTB	P	12	4.14	.201	159.8**
P(DSTB)		216	4.15	.162	48.1

[1] Seeds from coastal and inland regions in northern California were chilled for 90 days and sown in February, March, April, and May.

*, ** Statistically significant at the 5, 1 percent levels.

that is symptomatic of poor or spotty mycorrhizal development (Molina and Trappe 1984).

Early sowing obviously has specific advantages. In fact, the disease and stunting problems that have plagued past seedling crops in the Humboldt Nursery might largely be avoided by simply shifting to a sowing schedule that captures the natural germination environment.

Growth Gains with Early Sowing

Any assessment of the amount of growth gained by sowing early is determined partly by the trait measured and partly by the seed source examined (fig. 3). Thus, gains of 20 to 35 percent in seedling height were accompanied by gains of 30 to 45 percent in stem diameter, 65 to 110 percent in top dry weight, and 25 to 85 percent in root dry weight after pruning. Growth gains for inland sources MK and OK were much alike while those for coastal sources AL and KR differed. Top weight showed the greatest gain in all sources, and root weight kept pace in one coastal source (KR) but trailed notably in the other (AL).

Seed Source Lifting Windows

Early sowing may be essential if seed source lifting windows for 1-0 seedlings at Humboldt Nursery are to correspond approximately to those already determined for the standard 2-0 seedlings (Jenkinson 1984). Winter and early spring sowings (February, March) may capture enough of the potential growing season to allow 1-0 seedlings to approach dormancy in early autumn. The seasonal course of height growth in Humboldt Nursery suggests a sigmoid pattern in the winter sowings (February) and an exponential pattern in the late spring sowings (May). Exponential patterns seemed to characterize even the early and midspring sowings of the coastal GQ source, but not of the inland SA source (fig. 4). In early autumn, however, growth of both sources was slowing in the February sowing and accelerating in the May sowing. Such divergent rates suggest

Table 9. Effects of seed source and sowing date on the seasonal growth and stocking of 1-0 Douglas-fir in Humboldt Nursery (1985)

Seed source and sowing date	Seedling height (cm) Jul 22	Aug 19	Sep 16	Oct 21	Stem diam (mm)	Seedlings per ft^2
North Coast Range (GQ)						
Feb 19	6.82	11.12	17.48	22.47	3.49	18.6
Mar 21	4.85	8.39	12.70	18.20	2.94	21.7
Apr 23	4.32	7.13	11.32	16.49	2.65	25.9
May 17	2.88	4.62	6.24	10.92	1.92	29.3
Klamath Mtns, central (SA)						
Feb 19	7.72	12.68	16.92	19.50	3.40	24.6
Mar 21	5.08	8.88	13.00	16.42	2.77	27.8
Apr 23	4.41	7.36	11.35	14.28	2.42	27.2
May 17	3.37	4.83	6.41	9.07	1.74	29.2

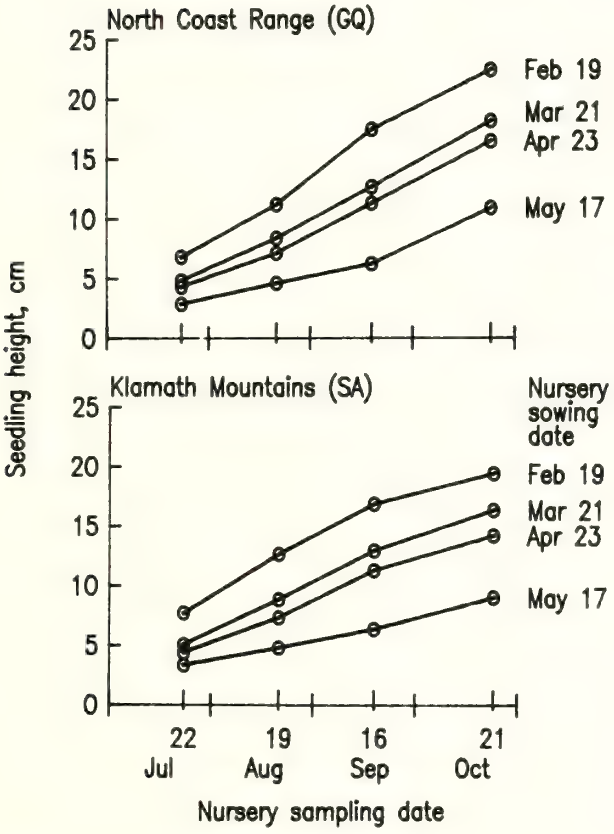

Figure 4. Sowing in winter compared to late in spring resulted in sigmoid rather than exponential patterns in the seasonal height growth of 1-0 Douglas-fir in Humboldt Nursery.

physiological states that respectively enhance and delay the autumn development of seedling dormancy, cold hardiness, and readiness for cold storage.

Winter sowing probably is essential if every source lifting window is to open at the same time for 1-0 as for 2-0 seedlings. Field survivals of 1-0 seedlings from April sowings have shown lifting windows that open later than those of 2-0 seedlings for nearby seed zones (Turpin and others 1985). And survivals of 1-0 seedlings from March sowings have shown windows that open as soon as, shortly after, or later than those of 2-0 seedlings planted in the same or nearby zones (Jenkinson 1984). Winter sowings are thus indicated if 1-0 seedlings are to achieve the physiological conditioning that is necessary to allow lifting and cold storage on the first safe date for 2-0 seedlings.

Seedling Size

Besides their physiological condition and storability, the size of 1-0 seedlings is a vital concern. No nursery wants to lift, and no forester wants to plant, thin-stemmed or whippy seedlings. Field experience suggests that 1-0 planting stock should be culled to a stem diameter of about 2.5 mm. In our March sowings, most seedlings of every seed source exceeded that standard. In 1979, stem diameters for sources AL, MK, KR, and OK averaged 2.8, 3.3, 3.8, and 3.0 mm, respectively, compared to 2.2, 2.6, 2.9, and 2.1 mm for the May sowing (table 7). In 1985, stem diameters for sources GQ and SA averaged 2.9 and

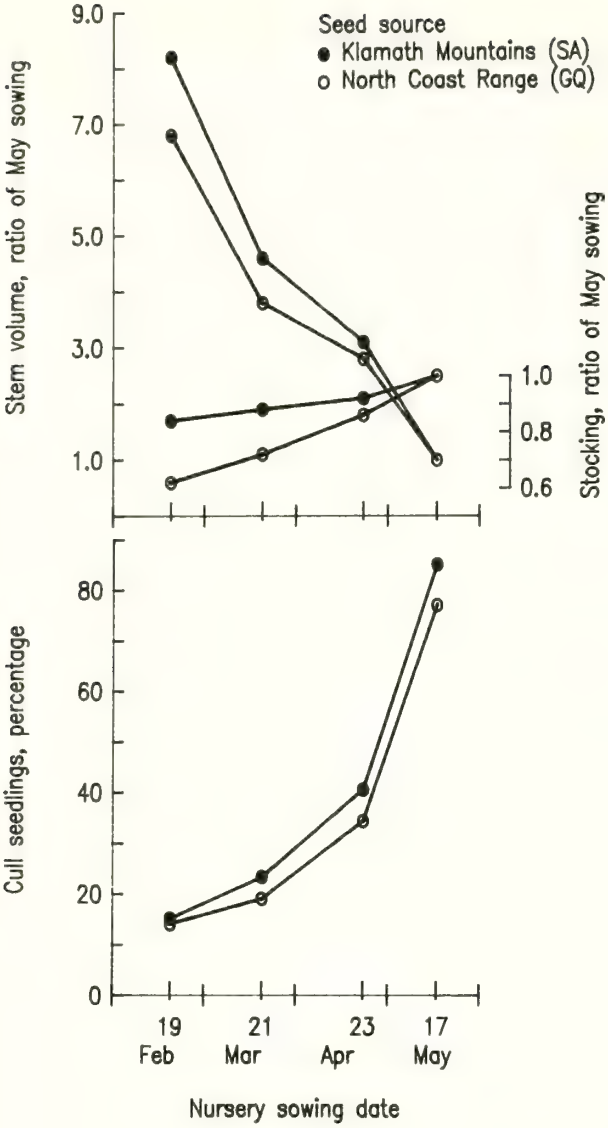

Figure 5. Sowing in winter compared to late in spring lowered seedling stocking by 18 or 34 percent, depending on seed source, but increased stem volumes seven- to eightfold and reduced cull percentages more than fivefold for 1-0 Douglas-fir in Humboldt Nursery.

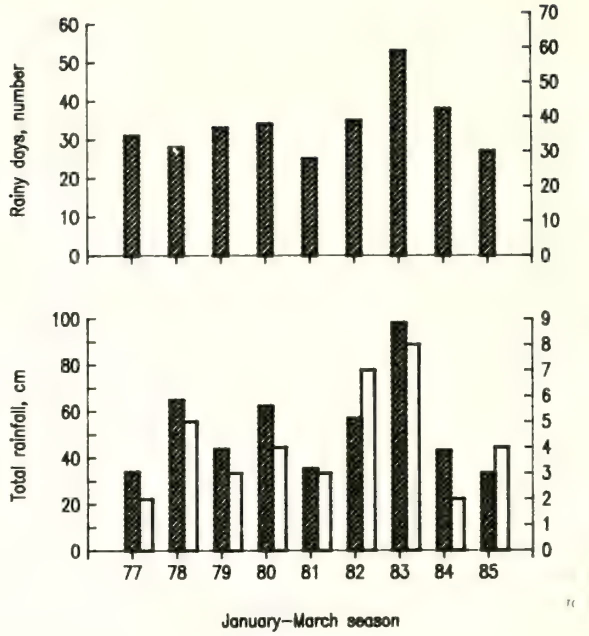

Figure 6. Weather patterns in January through March at Humboldt Nursery usually bring two to five heavy rainstorms and 50 to 65 clear days. The wettest period on record (1983) had eight heavy storms and 36 clear days.

Table 10. Effects of seed source and soil erosion control on the stocking of 1-0 Douglas-fir in Humboldt Nursery (1985)

Seed source	Seedlings per ft^2, by erosion control method [1]			
	None	Hydromulch	Shade cloth	Mean [2]
North Coast Range (GQ)	19.4	24.1	27.4	23.6 b
Klamath Mtns, central (SA)	27.5	27.6	29.0	28.0 a
Mean [2]	23.4 b	25.8 ab	28.2 a	

[1] Values are grand means of inventories in July, August, September, and October.

[2] Means followed by different letters differ significantly at the 5 percent level.

2.8 mm, compared to 1.9 and 1.7 in the May sowing (table 9). Even modest increases in stem thickness mean substantial gains in the total dry matter of root-pruned seedlings, for example, 44, 57, 88, and 85 percent respectively in sources AL, MK, KR, and OK.

Early spring sowings (March) in Humboldt Nursery can produce large 1-0 seedlings that have wide seed source lifting windows and high potentials for plantation establishment (Jenkinson and Nelson 1983). Our 1985 test suggests that winter sowings may prove to be even better, however, because seedlings of both coastal and inland sources were about 75 percent larger in the February than in the March sowing (fig. 5).

Nursery Sowing Windows

With an improved capability for winter sowing, Humboldt Nursery might safely sow in January to produce 1-0 planting stock. The potential sowing window may span up to 3 months, from midwinter to midspring. The number of seedlings produced per hundred viable seeds will determine when the window opens, and the size of the seedlings produced will determine when the window closes. The last safe sowing date will usually fall in early April, assuming that 75 percent of the seedlings must have a minimum stem diameter of 2.5 mm (fig. 5).

The first safe sowing date will depend on the effects of early sowing and soil erosion control on seedling stocking. Sowing in February reduced the stocking of inland seedlings by one-sixth, and of coastal seedlings, by one-third, compared to sowing in May (fig. 5). Erosion control substantially improved stocking for the coastal source but not the inland source, with shade cloth increasing stocking by 41 percent in source GQ but by only 5 percent in source SA (table 10). Thus, any choice of a first safe date may have to balance the tradeoffs of lower stocking and larger seedlings that accompany earlier sowing. The date chosen should be one for which the possible reduction in stocking is slightly less than an accepted cull percentage, assuming that most seedlings in the earliest sowing will be large enough to outplant.

The greater effects of early sowing and erosion control on the stocking of coastal seedlings may be explained by the significantly smaller seeds of coastal sources. Air dry seeds were 23 percent smaller for the North Coast Range than for the central Klamath Mountains source (12.2 mg/seed, or 37,100 seeds/lb against 15.0 mg/seed, or 30,200 seeds/lb). Sowing depth is critical for the successful germination and emergence of Douglas-fir (Minore 1985), and the precise sowing and uniform maintenance of smaller seeds at 3 mm below the surface may be more difficult and less likely under winter conditions.

The smaller size of the coastal seeds may also explain why the coastal seedlings were consistently smaller than inland seedlings during the summer (table 9). By late autumn, however, coastal seedlings were larger than inland seedlings, reflecting their adaptation to length of growing season at seed origin.

CONCLUSION

Early spring and winter sowings of Douglas-fir over two separate years at the Humboldt Nursery have consistently resulted in plantable 1-0 seedlings for diverse seed sources in coastal and inland regions of western Oregon and northern California. We conclude that Humboldt Nursery can readily produce 1-0 Douglas-fir planting stock for most forest sites on the Pacific slope. To produce 1-0 stock efficiently, we recommend three practices:

- o Chill seeds at least 60 to 90 days to insure rapid and complete emergence in cool soil conditions.
- o Sow in winter and early spring to utilize all or most of the potential growing season.
- o Protect newly sown beds with hydromulch or shade cloth to control soil erosion and limit seed losses.

Studies are being repeated to determine the stability of nursery sowing windows for 1-0 stock and to firmly establish procedures that can preclude soil and seed losses. With the proper sowing schedule, seed source lifting windows can be as wide for 1-0 as for the highest quality 2-0 stock. Continued aggressive field evaluation of 1-0 stock is warranted because of its potential payoff in high survival and growth for less than the costs of 2-0 stock.

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Weed Control: Alternatives to Herbicides[1]

Edward Olson [2]

Abstract. In 1984 Federal use of herbicides was banned in Oregon and Washington. The purpose of this presentation is to outline the impact and response to the loss of herbicide useage at one USDA nursery, and to provide a brief look at the arsenal of tools and equipment used to keep unwanted vegetation at bay.

INTRODUCTION & BACKGROUND OF THE HERBICIDE BAN

On March 1, 1984, U.S. District Court Judge James Burns issued an injunction to the Forest Service in Washington and to both the Bureau of Land Management and the Forest Service in Oregon, enjoining them from applying herbicides in any of their vegetation management programs including nurseries, research projects, noxious weeds and individual tree treatments until the agencies could develop adequate NEPA documents, including worst case analysis.

Federal nurseries in the region were directed to defer the use of all herbicides by the end of March 84. Due to the wording of our pesticide use proposal which identified the herbicidal properties of soil fumigation as a positive tool in the control of unwanted vegetation, it was felt that the court could have interpreted the use of Methyl Bromide to be an application of an herbicide. Therefore, the decision was made by the nursery superintendent to discontinue the use of fumigation at Wind River Nursery.

At Wind River two consecutive bareroot crops totaling roughly 32 million seedlings were sown on unfumigated ground. In 1985 a resubmission of our use proposal identifying the fumigation targets of most significance as soil borne diseases, insects and other pests resulted in the approval to resume the use of soil fumigation. In 1985 we were able to fumigate approximately 1 acre of bedhouse area, and in the spring of 1986 we fumigated roughly 40 acres for spring bareroot sowing. We are still unable to apply any herbicides at Wind River.

At this time the herbicide ban on Federal lands in Oregon and Washington is still in effect. A herbicide Risk Assessment has been prepared by the Washington Office and it will be used in the preparation of several Environmental Impact Statements. As we understand the situation, Federal Nurseries and possibly the noxious weed programs are to be covered under separate EIS's that are being prepared by the Washington Office. At this time it appears that there will be a formal legal request for relief made in the fall of 1987. Much work remains to be done and it could be several years before we know the outcome of the litigation.

THE PREVIOUS STANDARD HERBICIDE PROGRAM AT WIND RIVER NURSERY

Prior to the injunction, herbicide useage at Wind River had been kept to moderate levels. Our annual program on the 1-0 crop consisted of one application of Stoddard's Solvent just prior to seedling germination (@25 gallon/acre), followed by one or two summertime applications of Dymid or Dacthal (@ 8 lbs/acre and 12 lbs/acre respectively). The 2-0 crop received only one shot of Dacthal or Dymid in the spring. Roundup had been used along the fences and in areas where the use of equipment was difficult. Fumigation had been done on areas for bareroot sowing, having a positive impact on subsequent weed populations. All other weed control was done either by manual or mechanical methods except that in 1981 we began using Chinese Weeder Geese. The philosophy of the weeding program at the time was to keep the seedling beds as clean as possible in order to eliminate competition for light, moisture and nutrients, and to keep weed seed contamination from adjacent areas to a minimum.

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[1] Paper presented at the Western Forest Nursery Council Meeting, Tumwater, Washington, August 12-15, 1986.

[2] Forester, Wind River Nursery, Carson, Washington.

THE POST INJUNCTION WEED CONTROL PROGRAM

The herbicide injunction arrived at a time when Federal nurseries were experiencing personnel and budget limitations. We could see that we needed new tricks to keep from being inundated with weeds. One of our first attempts in 1984 was to enter into personal services contracts with individuals willing to submit an hourly wage bid for their own personal labor. We simply took the lowest bidders until we had a crew of sufficient size. This worked well except that we received pressure from the National Federation of Federal Employees and the Washington Office of the Forest Service to discontinue the use of this type of labor force after only one year.

In 1985 and again this year we have had a program in cooperation with the Washington State Parks and Recreation Commission called the Youth Development and Conservation Corps. This program employs youths 14 thru 21 years of age at below minimum wage levels. In addition to their salary the enrollees receive work experience and conservation education. This program has been very successful so far, but, even with 40 enrollees we are unable to maintain the nursery fields as inexpensively and as cleanly as they had been prior to the ban. Nowadays, we must often be satisfied to weed only those weeds that are starting to bloom or are developing seed and move on to other priorty areas.

Over the years we have developed or purchased a wide variety of hand tools. Some of the more common ones are shown in these slides. A variety of mechanical equipment including the Turner Rear Mounted Flail Mower, the Fobro Brush Hoe, the Rotary Cultivator, the Rotera, Rototillers, various Weed Eaters, Troy Built tillers, the Bush Hog and even a Flame Thrower have been used for weed control.

We have had limited success with Biological Control. Of the various agents tried, we have had the most success with the weeder geese which was a presentation given at a previous meeting. Also, the county has released Cynabar larva in the general area in an attempt to combat the tansy ragwort. These larva also feed on groundsel, on of our biggest problem species. Although there are now large populations of Cynabar at Wind River, their impact on the groundsel has been minimal. Finally, manipulation of irrigation water is sometimes used during periods of peak seed dispersal to reduce their germination. We would be interested in hearing from anyone who has experimented with other forms of biological control.

COSTS

The injunction in early 1984 caught us by surprise. Our cost data from the years when there were few restrictions on herbicides was not detailed enough for a highly accurate breakdown of the weed control aspect of our program. However, we began keeping track of the situation on a more detailed basis early that spring and were able to compare the total cost of the previous program with the cost of operating under the injunction. It was determined that the total additional cost to our nursery was roughly $106,000 in 1984. Based on a production of around 20MM at that time, this raised our production costs by about $5.30 per thousand. This figure included the cost to our clients of the additional seed required to offset the expected (and experienced) increase in cull %, but did not include the cost to them of replenishing their seed inventory. Also, the competition for light, nutrients, water and space may have resulted in some less vigorous seedlings being shipped. In theory, if only 5% of the total production (or @ 1MM seedlings) failed to survive after outplanting as a result of the injunction, the additional cost of replanting could be as high as $700,000, based on a planting cost of $350 per acre @ 500 trees per acre. The increased production costs combined with the additional reforestation costs could result in a total additional cost of up to $20 per acre to our clients.

IN SUMMARY

We sincerely hope that the legal effort to gain relief from the current herbicide injunction will bring us back to a more realistic program of weed control by the spring of 1988. However, weed seed buildup in areas that we had had under control in the past will provide us with difficulties for years to come. In the meantime we are trying to stay ahead of the blooming weeds.

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Seedling Monitoring During the 1-0 Growing Season[1]

David Steinfeld [2]

Abstract.--Describes a method for measuring seedling growth characteristics and environmental factors in a conifer tree nursery during the first growing season and how this data can be used for culturing seedlings.

INTRODUCTION

Knowing how well the seedlings at your nursery are performing at any given time is essential for good nursery management. The systematic 1-0 monitoring plan presented in this paper is one way of obtaining that information.

PROCEDURES

The procedure for monitoring 1-0 seedlings at J. Herbert Stone Nursery is designed to evalutate (1) seedling growth and environmental factors at individual plots (intensive monitoring) and (2) the overall condition of the stock across the entire field (extensive monitoring). The intensive and extensive monitoring are performed together at weekly intervals.

Extensive Monitoring

The purpose of extensive monitoring is to observe the entire growing area for overall condition of the crop and to identify any problems. This is accomplished by planning a course of travel so that seedlings in the entire growing area are observed from no more than 40 feet away. A report is made upon completion of the walkthrough that addresses such things as stunted or chlorotic seedlings, poor germinating lots, insect and disease damage and plugged sprinkler heads. If any observations show up in a pattern, they are plotted on a map of the nursery. These maps are later used to correct the problems before sowing another crop in the same area. Field reports are circulated to appropriate nursery personnel to keep them abreast of the current condition of the stock.

Intensive Monitoring

The purpose of intensive monitoring is to record site factors and seedling growth trends at individual plots throughout the growing area. The plots are installed before seedling emergence. They are randomly located on the course of travel for the extensive monitoring in such a manner that all field conditions are monitored. Presently, we are monitoring approximately one plot per acre.

Data Collection

Mortality. A four by one half foot permanent sampling area is marked at each plot using plastic "popscicle stick" markers in each row of seedlings. Dead and alive seedlings within this area are counted weekly. After each count, dead seedlings are removed from the sampling area. Mortality is expressed as a percent of dead seedlings for the week of collection over the total seedling count for that sampling area at the end of the season (dead plus live count).

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[1] Paper presented at the Western Forest Nursery Council Meeting, Olympia, Washington, August 12-15, 1986.

[2] David Steinfeld is Cultural Assistant at J. Herbert Stone Nursery, Rogue River National Forest, Central Point, Oregon 97502.

Lygus Damage. In the same sampling area, all seedlings with Lygus damage in the top inch of the terminal leader are counted. Lygus is expressed as percent damaged over total seedlings in the plot for that week.

Bud Set. All seedlings in the sampling area are observed for bud set. This is expressed as percent budset over total seedlings.

Seedling Height. Plastic rings are placed at the base of ten seedlings at each plot. Height is determined by measuring from the base of the tagged seedling to the growing tip of the terminal leader. Height can be expressed as either total mean height or mean incremental growth for that week.

Surface Soluble Salts. Salts rising to the surface due to capillary action is a problem at this nursery. We believe that the high salts have lead to mortality and stunting of several species of seedlings. Monitoring the surface salt levels helps us determine when to irrigate to bring the soluble salt levels down to acceptable levels for plant growth and survival.

Soil within 1/2 inches of the surface is collected from undisturbed areas outside of the sampling points. Electrical conductivity is measured at our facilities using a "quick test" for electric conductance (Wilde 1979).

Soil Moisture. At each plot, a permanent soil tensiometer is placed at 5 inches and read at least twice a week. Soil moisture as determined by the gravimetric method is collected occasionally at each plot.

Other Data Collected. Later in the summer, several of these plots are used as sampling areas for predawn plant moisture stress readings. Also, each of these plots are withing 40 feet of a permanent soil nutrient sampling point. These soil sampling points are areas where soils are collected in the fall before sowing and sent to a lab for a complete soil nutrient analysis.

Use of Intensive Monitoring Data For Nursery Management

Plotting growth, site factors, and cultural manipulations over time will show annual growth trends in relation to cultural and site factors. With several years of growth trend data, a manager can develop an idea of what to expect from the current 1-0 crop and what measures, if any, to take to produce the desired seedling for that year.

For example, the 1-0 crop in our 1985 field was several inches higher than desired. Using the 1985 data, we were able in 1986 to produce a shorter seedling by scheduling the last irrigation to be several weeks earlier than the last irrigation in 1985. This would not have been possible if we had not known the growth trends for the previous years irrigation schedule.

Understanding how site conditions affect seedling growth can lead to a better manipulation of the seedling environment to produce the desired seedling. Using two years of data, we have been able to characterize the moisture regimes for the optimum growth of several species. This has lead to a better irrigation schedule for all of our stock.

Evaluating site conditions and seedling growth can also clarify specific nursery problems. We have been able to determine when and to what extent Lygus is damaging certain species. This understanding has lead us to better control of this insect.

DISCUSSION

1-0 monitoring does not take the place of an inventory, nor should the data be used for calculating survival factors. The sample size is too small. There is some question as to whether we are collecting enough data to give us a clear picture of trends. We intend to pursue this question. Nevertheless, our initial intention of monitoring was to make sure that the entire field was observed weekly in a relatively unbiased fashion. We feel that this monitoring system meets this objective at the least expense.

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Growing Seedlings on a Production Scale in a Shadehouse[1]

Thomas M. Smith[2]

Abstract.--In Albuquerque, New Mexico five (5) crops (approximately 400,000 seedlings) of ponderosa pine (Pinus ponderosa, Rocky Mountain form) were grown in single 30'X96' greenhouse from January 1985 to December 1985.

INTRODUCTION

On January 3 & 4, 1985 crop number one was sown using Acoma, New Mexico, and Zuni, New Mexico seed sources. Crop number one was moved to the shadehouse on May 3, 1985. Crop number two was sown on May 6 & 7, 1985 using a Zuni, New Mexico seed source, and moved to a shadehouse on June 7, 1985. Crop number three was also a Zuni, New Mexico source sown on June 10 & 11, 1985, and moved to a shadehouse on July 10, 1985. Crop number four was a Jicarilla, New Mexico seed source sown on July 15 & 16, 1985, and moved to the shadehouse on September 6, 1985. Crop number five, a Santa Clara, New Mexico seed source was sown on September 9 & 10, 1985 and moved to the shadehouse on December 23, 1985.

All seedlings were ponderosa pine (Pinus ponderosa, Rocky Mountain form). Spencer-LeMaire Tinus (21.5 cubic inches) Roottrainers were used. Each crop was approximately 80,000 seedlings. The Bureau of Indian Affairs (BIA) greenhouse located in Albuquerque, New Mexico was used.

DISCUSSION AND RESULTS

The Bureau of Indian Affairs greenhouse in Albuquerque, New Mexico is a 30'X96' doublepoly Nexus style greenhouse. The growth fertilizer was Peters 20-20-20, and Peters 9-45-15 was used after flushing and stressing, Peters STEM was added to every fertilizer application for trace elements. None of the seed was stratified.

Crop number one was sown on January 3 & 4, 1985 and grown using the usual procedure for the BIA facility in Albuquerque, New Mexico. Table 1 details the procedure.

TABLE 1, Normal Water & Fertilizer Program

Wk	Stage of Crop	Boom Passes	Time	Fertilizer (20-20-20+STEM)
1	Germination	2	Daily am & pm	None
2	Germination	2	Daily am & pm	None
3	Juvenile	5	M-W-F am	M-W ½ lb #3 Pass
4	Juvenile	5	M-W-F am	M-W 1 lb #3 Pass
5	Juvenile	5	M-W-F am	M-W 1½ lb #3 Pass
6*	Exponential	5	M-W-F am	M-W 2 lb #3 Pass

*Remains the same until flushing and stressing then 2 lbs 9-45-15+STEM substituted for 20-20-20.

The crop was moved to the shadehouse on May 3, 1985, and outplanted in August and September, 1985 when soil moisture was adequate.

On May 6 & 7, 1985, crop number two was sown and moved to the shadehouse on June 7, 1985. The crop had been thinned and transplanted and was about to begin the exponential growth stage by that time. The greenhouse water and fertilizer schedule was maintained until the crop was flushed on September 23, 1985.

Crop number three was sown June 10 & 11, 1985 and moved to the shadehouse on July 10, 1985. As with crop number two this allowed time for thinning, transplanting and the beginning of the exponential growth stage. This crop was also maintained on the exponential water and fertilizer schedule until September 23 flushing.

Crop number four was sown on July 15 & 16, 1985 and kept in the greenhouse until September

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[1] Paper presented at Western Forest Nursery Council Meeting [Tumwater, Washington August 11-15, 1986.]

[2] Thomas M. Smith is Forest Development Officer, Bureau of Indian Affairs, Southern Pueblos Agency, Branch of Forestry, Albuquerque, New Mexico.

1985. This was to allow additional development under greenhouse conditions prior to the onset of winter. This crop was also flushed on September 23, 1985.

Flushing on September 23 was done to allow natural hardening off to occur in the shadehouse. Watering was cut back to twice per week and fertilizer with 2 lbs 9-45-15+STEM.

Crop number five was sown on September 9 & 10, 1985 and moved to the shadehouse on December 23, 1985. The house was flushed on November 15 and the hardening off procedure was begun at that time.

Throughout this accelerated program only two environmental problems occurred.

Spring cottonwood seed drop created a large thinning problem in the shadehouse. Crop number two had 1 pine seedling and from 5-10 cottonwood seedlings. Only crop number two was affected. Shadecloth over the shadehouse roof during seed fall, should reduce this problem in the future.

After flushing the shadehouse, for Albuquerque, it rained quite frequently. There were several small stressings instead of one long one. The seedlings developed all the usual signs of stressing.

Root tip elongation was first noted on March 3, 1986. Shoot elongation was first noted on April 1, 1986 for May, June and July crops, elongation for September crop began on April 14, 1986. Shoot elongation tends to be later when a crop is forced into dormancy in a greenhouse, in Albuquerque.

CONCLUSIONS

The accelerated growth schedule using the greenhouse in Albuquerque, New Mexico as a germinator worked very well on a production scale. The seedlings developed to a stage enabled them to overwinter under shadehouse conditions. Further research regarding field survival needs to be done.

Some Effects of Cold Storage on Seedling Physiology[1]

Gary A. Ritchie[2,3]

Abstract.--When tree seedlings are lifted from the nursery in winter and placed into cold storage they are no longer exposed to the natural environmental factors which provide energy for growth and information for phenological development. This affects many important physiological variables which influence seedling quality. This paper summarizes several years of storage physiology research on Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) conducted by Weyerhaeuser Company.

Stored carbohydrates are depleted, dormancy release is slowed, and cold hardiness is gradually lost in cold storage. Root growth potential may increase, decrease or remain constant depending on lift date, storage duration and species. Effects of cold storage on seedling water relations have not been adequately investigated.

INTRODUCTION

Cold or frozen storage of planting stock enables nurserymen and foresters to bridge the gap between fall or winter lifting and spring planting. Because of this it has become an invaluable tool in forest regeneration operations in the Pacific Northwest.

In the natural outdoor environment tree seedlings are exposed to strong diurnal fluctuations in air and soil temperature, light intensity and duration, soil and atmospheric water status, and other factors. Over the millenia tree species have adapted to use these factors as sources of both energy for growth and information for driving phenological development (Campbell 1978).

When seedlings are lifted from the nursery or greenhouse and placed into cold, dark storage they no longer experience these environmental changes. Rather, temperature remains low and constant, light is absent, and humidity is very high.

This paper will consider some important physiological processes and variables and outline the manner in which they respond to the cold storage environment. It is based almost entirely on our research and experience with coastal Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) seedlings at Weyerhaeuser. When available and pertinent, data from other conifers are also cited. The focus of the review is on seedling quality.

PHYSIOLOGICAL VARIABLES AFFECTED

Enumerable physiological processess and variables affect seedling physiological quality. Among those which are strongly affected by cold storage are: (1) carbohydrate reserves, (2) bud dormancy status, (3) root growth potential, (4) cold hardiness, and (5) water relations.

Carbohydrate Reserves

Nearly all plant food reserves are stored in the form of starch and sugars. These are produced ultimately by photosynthesis and are consumed by respiration to sustain plant growth and metabolism. Both photosynthesis and respiration are strongly temperature-dependent and photosynthesis requires light.

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[1] Paper presented at the Western Forest Nursery Council Meeting, [Tumwater, Washington, August 12-15, 1986].

[2] Gary A. Ritchie is Research Project Leader, Western Forestry Research Center, Weyerhaeuser Company, Centralia, WA.

[3] The author thanks Dr. Nicholas Wheeler for reviewing and Ms. Joan Ruthford for preparing this manuscript.

Cold storage impacts photosynthesis and respiration in two ways. First, absence of light stops photosynthesis; second, low temperature decreases the rate of respiration. The net effect is that seedlings burn up their supply of reserve carbohydrates in storage - but they do so very slowly. In an experiment with 2+0 Douglas-fir, total non-structural carbohydrate (TNC) concentrations in January were highest in foliage (Ritchie 1982). During the first two months of storage foliar TNC was respired more rapidly than stem or root TNC (fig. 1.). During the following 10 months a near-linear decrease in TNC occurred in all tissues - the result being that during one year the seedlings had consumed roughly half their food reserves. Storage temperature also affects the rate of loss of food reserves. Douglas-fir seedlings stored at -2°C contained about 2.5 mg/g more TNC after 6 months than did those stored at +2°C (Ritchie, unpublished data).

It would be valuable to know how much food reserve is necessary to ensure survival and adequate early growth but this information is not yet available. As a first approximation, 10 to 12 mg/g might be a reasonable estimate.

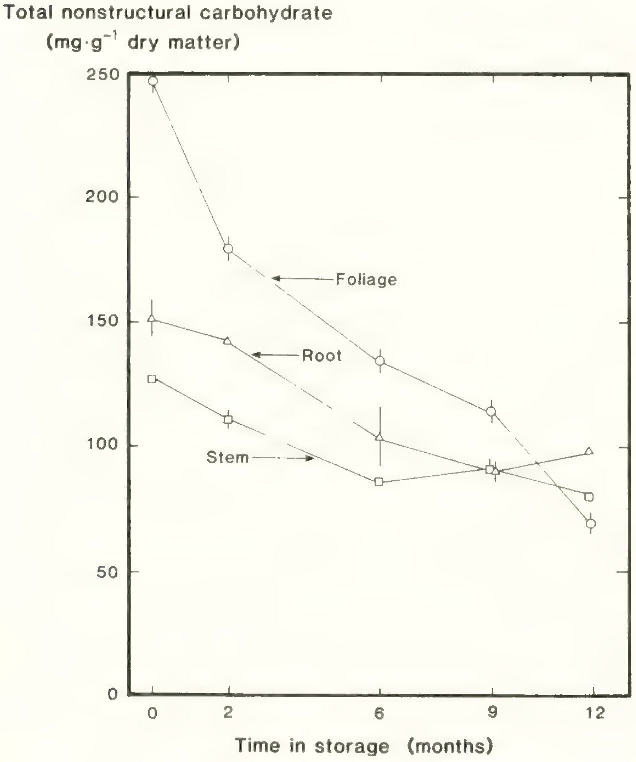

Figure 1.--Changes in total nonstructural carbohydrate concentrations in foliage, stems, and roots of 2+0 Douglas-fir seedlings lifted January 27, 1978 and stored at -1°C. Vertical bars = + 1 standard error. Reproduced with permission from Canadian Journal of Forest Research 12(4): 908, 1982.

Bud Dormancy Status

By late fall (October) in the coastal Pacific Northwest, conifer seedlings normally will have reached the peak of dormancy (Lavender 1985). As winter progresses, continual exposure to temperatures below about 6°C (chilling) acts to release dormancy. By March dormancy release is complete and seedlings will break bud and begin growing upon exposure to warm, spring-like conditions.

This progress through dormancy to dormancy release can be visualized by plotting a "Dormancy Release Index" (DRI) curve over the accumulation of hours of chilling temperatures. DRI for Douglas-fir is calculated as the number of days to terminal budbreak of seedlings held in a warm, forcing environment (DBB) divided into 10 (Ritchie 1984). As dormancy release progresses through winter the DRI value approaches unity. This relationship is shown for 2+0 Douglas-fir seedlings of four seed zones in figure 2.

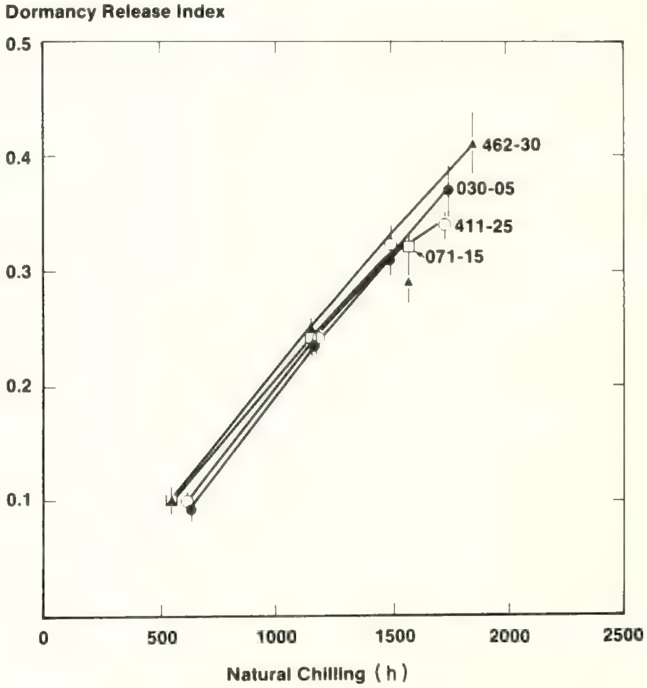

Figure 2.--Dormancy release index in 2+0 Douglas-fir seedlings as a function of natural (nursery) chilling. Data are for the winter of 1979-1980. Each point is a mean (± standard error) of 15 seedlings held in a forcing environment. A chilling hour is defined as one during which the air temperature is below 6°C. Reproduced with permission from Canadian Journal of Forest Research 14(2): 188, 1984.

When seedlings are lifted from the nursery and placed into cold storage several things occur which affect this relationship. First, seedlings are exposed no longer to daily fluctuating light and temperature; and second, they are held at a temperature which is apparently not very efficient at releasing dormancy. The net effect is that dormancy release does occur - but at a much reduced rate.

In the experiment illustrated in figure 3 we lifted Douglas-fir seedlings on four dates during winter and determined their DRI value. These are plotted as circles on the figure. We then held back samples of these seedlings for storage at -1°C for two [□] and six [△] months, then removed them and again determined the DRI values. In each case, seedlings were far more dormant following storage than they would have been had they been allowed to remain in the nursery beds. Similar experiments were performed with lodgepole pine (Pinus contorta Dougl.) and interior spruce (Picea glauca-engelmannii complex) with similar results (Ritchie et al. 1985) suggesting that this may be a relatively common response in many conifers.

The practical implication of this phenomenon is that one can lift stock in fall or winter when it is dormant and hold it in a dormant condition well into spring for spring planting. It is primarily because of this relationship that cold storage works as well as it does.

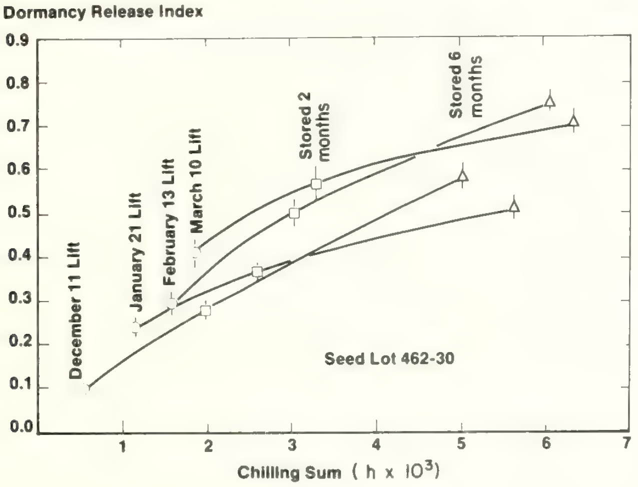

Figure 3.--Dormancy release index in 2+0 Douglas-fir seedlings from a western Oregon Cascade seed zone during winter of 1979-1980. Seedlings were lifted at four times during winter and stored at -1°C for 2 or 6 months. Chilling sum is the sum of nursery chilling plus hours held in storage. Reproduced with permission from Canadian Journal of Forest Research 14(2): 188, 1984.

Root Growth Potential

Root growth potential (RGP) is not a physiological process per se. However, it integrates many important physiological processes in the seedling and, for this reason, has become a popular and useful indicator of seedling vigor. The rationale is that if there is any problem with the seedling physiologically it should show up as a decrease in the seedling's ability to produce roots.

RGP is strongly affected by cold storage. In 2+0 Douglas-fir a very clear pattern has emerged over several seasons of testing. RGP is low in fall and early winter, increases and peaks in December and January, then decreases in February to a low in March. With respect to cold storage: two-month storage is nearly always beneficial - the greatest benefit being gained with fall and early-winter lifted stock, while six-month storage is rarely beneficial - especially when stock is lifted in late winter or spring.

This relationship is apparently not universal, however. In a study with lodgepole pine and interior spruce (Ritchie et al. 1985) quite different patterns were observed (fig. 4). The reasons for these differences are not

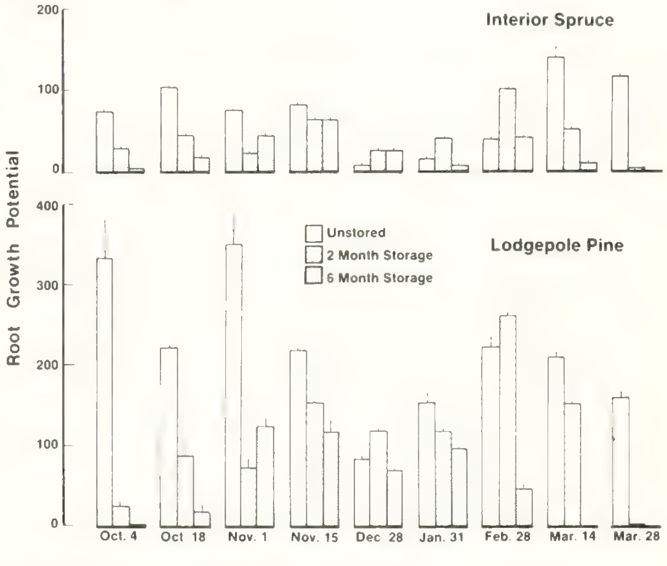

Figure 4.--Root growth potential (number of new roots per seedling) of 2+0 lodgepole pine and interior spruce seedlings lifted throughout winter from a central British Columbia nursery. Seedlings were tested immediately after lifting and after 2 and 6 months in -1°C storage. Each value is a mean (standard error) of 20 seedlings. Reproduced with permission from Canadian Journal of Forest Research 15(4): 639, 1985.

known and until the underlying mechanisms driving RGP are understood it will probably be necessary to develop this information for each species and, perhaps, each nursery as well.

Cold Hardiness

A seedling's ability to endure subfreezing temperatures varies dramatically over the course of the year. In summer exposures to -5°C are sufficient to kill Douglas-fir seedlings. But in mid-winter these same seedlings can easily withstand temperatures below -20°C. With hardier northern species such as white spruce (Picea glauca (Moench.) Voss) and lodgepole pine, midwinter hardiness can approach -80°C.

Hardiness develops in fall in response first to shortening photoperiod then to increasing exposure to cold nights (Glerum 1985). As nights become increasingly colder, seedlings become more and more hardy. Increasing photoperiod and higher temperatures in spring cause seedlings to lose hardiness rapidly. This is why late frosts can be so damaging.

One would suspect that removal of a seedling from these environmental signals by placing it in cold storage would interfere with the development of natural hardiness. Further, since carbohydrate reserves undergo a net loss during storage and since hardiness development requires an expenditure of metabolic energy, one would expect a loss of hardiness with time in storage.

Unfortunately, very little information exists on the effect of cold storage on hardiness in tree seedlings. However, the limited data which do exist (table 1) tend to confirm the above predictions. Seedlings lifted early in winter while hardiness was developing did not continue to harden in storage - rather they slowly lost hardiness. Seedlings lifted in spring continued to deharden in storage.

More research is needed on this question for it has important implications. Suppose, for example, that seedlings are fall-lifted for mid-winter planting. If they have not developed adequate hardiness before lifting and are planted on a very cold site they might suffer considerable winter damage. One

Table 1.-- Estimated values of LT_{50} (deg. C)[1] for lodgepole pine and interior spruce seedlings at time of lifting and following 2 or 6 months in storage at -1°C. Reproduced with permission from Canadian Journal of Forest Research 15(4): 640, 1985.

Date Lifted	Storage Period (months)	Date Tested	Lodgepole Pine	Interior Spruce
October 4, 1982	0	October 4, 1982	(-20)[2]	(-26)
	2	December 4, 1982	(-14)	-27
	6	April 4, 1983	----	-14
November 1, 1982	0	November 1, 1982	-29	-30
	2	January 1, 1983	-26	-26
	6	May 1, 1983	-20	-25
March 28, 1983	0	March 28, 1983	-18	<-18
	2	May 28, 1983	(-11)	<-18
	6	September 28, 1983	-7	<-18

[1] LT_{50} = lethal temperature for 50% of the test population.

[2] Values in parentheses are extrapolations, others are interpolations of percent injury over temperature curves from whole-plant freeze tests.

wonders how much overwinter damage can be attributed to this cause. On the other hand, seedlings which are lifted in winter can be held well into spring for high elevation planting where exposure to low temperatures is expected. In the table 1 data, for instance, seedlings lifted in November were still hardy to -20° or -25°C when tested the following May.

Water Relations

Seedling water relations are very complex and a complete discussion is far beyond the scope of this paper. Suffice it to say that during mid-winter conifers exhibit very "favorable" water relations properties -- i.e. they are able to tolerate substantial desiccation of both tops and root systems without incurring appreciable damage (Ritchie and Shula 1985, Ritchie 1986). By spring (March) when growth begins, water relations properties shift abruptly to a far less favorable status and seedlings become very sensitive to water-related stresses. The success of the mid-winter lifting window may be due in part to these highly favorable seedling water properties.

The question is: what effect does storage have on seedling water status? Do seedlings maintain favorable water status in storage or does water status deterioriate? Unfortunately this question has not been researched. One might speculate, however, that since carbohydrates are depleted in storage, and since water relations reflect osmotic relations which depend to a degree on dissolved carbohydrates in the cells, that we would see a gradual deterioration of seedling water status with time in cold storage. This might partially explain why storage beyond six to nine months almost invariably results in poor performance of planting stock. This is an interesting and important question and deserves to be investigated.

SUMMARY AND CONCLUSIONS

When tree seedlings are held in cold, dark storage for prolonged periods of time they are separated from the sources of environmental energy and information they need to develop in synchrony with the changing seasons. This affects many important physiological processes and variables.

Effects of cold storage on dormancy release, carbohydrate depletion and root growth potential have been studied and are reasonably well understood - at least in an empirical sense. Effects on some other important variables such as cold hardiness and water relations are less well known.

On balance, positive effects of cold storage heavily outweigh negative effects, hence it has become a widespread and very useful practice throughout most of the Pacific Northwest.

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Freezer Storage Practices at Weyerhaeuser Nurseries[1]

Stephen M. Hee[2]

Abstract.--The storage of conifer seedlings in freezer units at a temperature of -2°C has become a matter of routine practice at Weyerhaeuser Forest Nurseries in Washington and Oregon. This paper provides background information on the evolution of this practice in Weyerhaeuser and describes current operating procedures.

NEED FOR LONG-TERM SEEDLING STORAGE

The need for long-term storage of seedlings in our Washington and Oregon operating areas exists for a number of reasons. Our nursery facilities west of the Cascade Range are situated at low elevations, less than one thousand feet. At these nurseries, seedlings must be lifted between December and early March in order to take full advantage of their frost hardiness and root regeneration potential. Because some of our planting sites at higher elevations are not accessible until May or June, storage periods of two to six months are common.

For our nursery in the Klamath Basin east of the Cascades, situated at four thousand feet elevation, spring lifting is often confined to four to six weeks duration because of winter freeze up and late thaw conditions. Long-term freezer storage allows lifting during late autumn and shipping the following spring. This provides for a more balanced work load, split between the fall and spring, and enables shipping to planting sites which thaw earlier than the nursery during the spring.

It has been our experience that shipping orders from the field can fluctuate widely depending on weather conditions and crew logistics. We attempt to operate our nursery lift and pack operations on a constant production flow basis and find that freezer storage provides us with such options as lifting in advance of field outplant orders and packing seedlings for transplanting when there is slack in outplant orders. Thus the freezer provides us with an effective surge buffer between nursery and field production.

DEVELOPMENT AND TESTING

During the early and middle 1970's most of our long-term storage needs were met using conventional cold storage methods where storage temperatures are kept at +1°C to +2°C and relative humidity conditions at 85% or higher. Though these conditions held seedlings satisfactorily for the most part, we did experience some problems with storage molds and fungi. Naturally the more mud and dirt included in the packing bags, the larger the problem with storage fungi. In an effort to eliminate this problem, we decided in 1976 to explore the alternative of storing seedlings at a temperature just below freezing, -1°C to -2°C.

In 1977, we lifted various lots of coastal and cascade source seedlings during mid January, divided these into two groups and placed one group into the freezer for storage at -2°C and the remaining group into the cooler at +2°C (Gutzwiler, 1978). Coastal lots were held in storage for six weeks and cascade lots were stored for six months. At the end of the storage period, the coastal lots were outplanted at a site in our Twin Harbors Tree Farm and the cascade lots were outplanted at our Vail Tree Farm. In the Twin Harbors test, both freezer stored and cooler stored coastal lots survived at 100 percent. For the cascade sources at Vail, no significant differences between cooler storage and freezer storage for like seedlots were observed (Table 1).

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[1] Paper presented at the Western Forest Nursery Council Meeting, [Olympia, Washington, August 12-15, 1986].

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Similar tests were conducted with ponderosa and lodgepole pine at Klamath in 1978 comparing freezer stored seedlings with cooler stored (Stevens and Heninger, 1986). Here seedlings were lifted in mid October, stored overwinter then outplanted in late April at Buck Mountain and mid May at Coyote creek the following spring. Survival percentages (Table 2) indicate no significant differences in performance between freezer and cooler storage for either species.

Table 1.--Survival percentage of seedlings stored in the cooler versus freezer for six months and outplanted at the Vail Tree Farm in 1977. Standard errors shown in parenthesis.

	North Aspect		South Aspect	
Species Class	Cooler	Freezer	Cooler	Freezer
Douglas-fir / 2+0	85 (5)	90 (3)	23 (8)	15 (5)
Douglas-fir / Plug	94 (2)	91 (4)	40 (1)	31 (8)
Western Hemlock / 1+1	50 (3)	53 (4)	2 (2)	3 (2)

Table 2.--Survival percentage of pine seedlings stored overwinter in the freezer versus the cooler and outplanted at the Klamath Tree Farm in 1978. Standard errors shown in parenthesis.

Species	Cooler	Freezer
Ponderosa Pine	87 (8)	84 (10)
Lodgepole Pine	88 (10)	93 (6)

A year later, additional tests were performed using coastal and cascade Douglas-fir lots, a noble fir lot and western hemlock lot. These were lifted in mid January at our Mima Nursery and stored in the freezer for intervals of zero, two, four and six months. After the designated storage period these seedlings were outplanted in a research test area at the nursery except for the six months stored treatment. The latter was potted and evaluated in the greenhouse because by then (mid July) the soil in the research test area had become excessively dry. The results of this test showed no significant decrease in survival percentages with time in freezer storage up to six months (Table 3). This applied across all three species tested.

Initially, we were somewhat concerned over how seedlings for the freezer should be packaged. We knew that the freezer could desiccate the seedlings if the moisture barrier provided by the packaging was not adequate. We, therefore, experimented with a number of different options (Gutzwiler, 1978). These included using:

the standard ply kraft bag (50#WS+10#PE/50#WS/50#WS),

the standard bag with its seam waxed dipped (50#WS+10#PE/50#WS/50#WS + waxed seam),

the standard bag plus a 1.5 mil poly liner (50#WS+10#PE/50#WS/50#WS + liner)

and the standard bag with the wax dipped seam plus the poly liner (50#WS+10#PE/50#WS/50#WS + waxed seam +liner).

Acceptable results were obtained with all treatments and the additional safeguards of the wax dipped seam of poly liner were not justified (Table 4).

Table 3.--Survival percentage of seedlings stored for 0 to 6 months in the freezer versus the cooler and outplanted at the Mima Nursery test area in 1978. Standard errors shown in parenthesis.

		Months in Storage			
Species	Seedlot	0	2	4	6[1]
Douglas-fir	411-15-01	100 (0)	100 (0)	100 (0)	95
Douglas-fir	030-05-01	100 (0)	100 (0)	99 (2)	100
Noble fir	430-20-04	98 (4)	99 (2)	86 (7)	100
Western Hemlock	412-30-02	78 (16)	100 (0)	95 (5)	100

[1] Evaluated in greenhouse.

Table 4.--Survival results for various packing bag treatments.

Bag Treatment	Survival (%)	S.E.
50#WS+10#PE/50#WS/50#WS	97	(1)
50#WS+10#PE/50#WS/50#WS + waxed seam	94	(3)
50#WS+10#PE/50#WS/50#WS + liner	97	(2)
50#WS+10#PE/50#WS/50#WS + waxed seam + liner	94	(1)

CURRENT FREEZER STORAGE PRACTICE

The use of freezing temperatures for long-term seedling storage has become a routine practice for our nurseries since 1978. We currently store about 25 million seedlings annually in freezers. Over the years we have found that the species which can be freeze stored at -2°C are numerous. A partial listing of those species which we have successfully freezer stored is presented in Table 5.

Table 5.--Some species which have been successfully stored in the freezer.

Douglas-fir
Noble Fir
White Fir
Shasta Red Fir
Grand Fir
Balsam Fir
Pacific Silver Fir
Fraser Fir
Western Red Cedar
Western Hemlock
Sitka Spruce
Englemann Spruce
Norway Spruce
Ponderosa Pine
Lodgepole Pine
Scots Pine
Western White Pine
Eastern White Pine
Western Larch
Giant Sequoia
Western Red Alder
Quaking Aspen
Oregon Grape
Eastern Red Maple

Some basic elements that are important in the freeze storing of conifers include physiological condition of the seedlings, packaging and thawing before planting. As with conventional cold storage it is always advisable to start with seedlings which are clean, healthy and disease free. Though most fungi will not grow and spread in freezer storage these will still be viable when the trees are removed from storage for thawing and planting.

The seedlings should be exposed to natural chilling conditions which occur in autumn in order to promote dormancy and frost hardiness. In our nurseries west of the Cascades, we find that by the first to second week in December virtually all seedlings are hardy to -5°C and LT_{50}'s of -10°C are not uncommon. At our Klamath nursery these conditions will occur at least a month earlier. Once seedlings attain these levels of hardiness they will store well under freezing conditions at -2°C.

The freezer storage facilities which we use are simply conventional refrigerator units which are operated at -1°C to -2°C. There are no provisions in these units for humidity control and since the evaporators are placed directly in the storage areas themselves the humidity will be quite low. It is therefore important to provide a moisture barrier in the packaging of the seedlings. Storage of seedlings in exposed bales will not work as the trees will desiccate.

We pack seedlings in both bags and boxes depending on customer preference. The bags are standard kraft seedling bags which are widely used by Washington and Oregon forest nurseries. These bags are of 3-ply construction with the inner ply treated with a 10# polyethylene spray coating. This coating provides a suitable moisture barrier. Seedlings are packed in the bags in a moist (not waterlogged) condition and the bag is sealed by folding and rolling the top down. The application of two or three straps secure the package. These are then placed on pallets with racks that allow for stacking and the entire palletized stack is moved directly into the freezer.

In the case of boxes, we use a 1.5 mil poly liner placed inside the box to prevent loss of moisture. The liner is sealed by twisting and tucking and is held secure by the top flap. Once palletized the boxes of seedlings are moved directly to the freezer.

Whatever is used to package the seedlings must provide a seal against moisture loss and be durable enough to withstand normal impact and abrasion in the production operation without sustaining tears and punctures. Should a bag or box be punctured, it can be patched with tape provided a wax coated surface is not involved. Wax surfaces are a challenge to repair.

Freezer temperatures should be checked daily and maintained at -1°C to -2°C. A continuous measuring device such as a thermograph is recommended as it provides the operator with a permanent record of temperature over time. Once in the freezer, seedlings may take up to ten days before they freeze solid. Plug seedlings will take longer than bareroot because of the potting soil and additional moisture contained in the root plug. Seedlings handled and packed in the manner described will keep well up to six months in the freezer.

Seedlings must be thawed before they are planted as frozen root systems or stems can cause transpirational drought stress. We thaw seedlings at the nursery before they are shipped to the customer. Thawing is done in a warehouse or similar structure at ambient temperature (+10°C to +15°C). The pallets are spread out to allow for ample air circulation between pallet stacks. Bareroot seedlings normally take three to five days for thawing whereas plug seedlings will require ten to fifteen days. Once thawed, the seedlings can be shipped to the customer for planting. It is preferable to plant seedlings as soon as they have thawed, however, our experience to date shows that they can be held in cooler storage after thawing up to four weeks without detriment.

SUMMARY

Storing seedlings at -2°C is a practical and proven means for holding conifers in a dormant, viable condition for periods up to six months before planting. Though cooler storage at +2°C can provide similar results the probability of problems with storage molds is much greater. Most western conifers can be freezer stored provided they are in a dormant and hardy condition before lifting and storing. Packaging seedlings for the freezer must include a moisture barrier. A polyethylene bag placed in the packing box or a polyethylene coating applied to the inner ply of the packing bag serve well in this function. Unlike cooler stored trees, freezer stored seedlings require thawing. This step is most practically achieved by simply spacing pallets of seedlings out in a warehouse at +10°C to +15°C.

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Seed Laboratory Computerization: A Database for the Forest Tree Seed Industry[1]

RODGER DANIELSON[2]

Abstract.--Recent computerization of the Oregon State University Seed Testing Laboratory has created a large, expanding database. The computer system and benefits of the resulting database to the forest industry are discussed.

INTRODUCTION

In 1984 the Oregon State University Seed Testing Laboratory began to look at computers to replace their aging mechanical card/tape system of recording and storing data.

A Masters candidate (Alberto Maristany) was hired on a half-time basis to design, develop and implement a computer system to meet the needs of the laboratory. His copyrighted programs were named Seed-Lab and have application for use in any seed laboratory. More complete details of his work may be found in a paper by Maristany and Danielson (1986).

The purpose of this paper is to describe the computer system and benefits it may have for the forest tree seed and nursery industries.

SYSTEM

Figure 1 is a schematic showing the flow of samples through the lab and the flow of information through the system of networked computers.

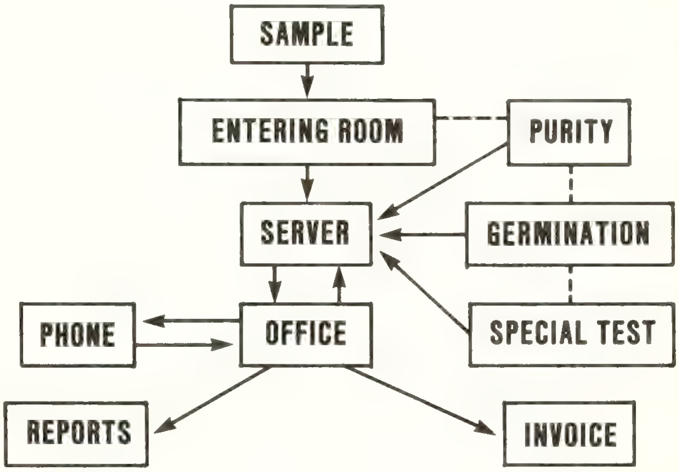

Figure 1.--Diagram showing flow of samples and information through the Seed Lab and computer system.

Samples are received in the entering room. Information pertaining to the samples (i.e. kind of seed, lot number, etc.) is entered into the computer system at this point and is stored on the hard disk of the central file server. Laboratory cards are generated for internal use by analysts to record their results. Samples then move to purity, germination, or special testing for various quality tests. Results of these tests are entered into the computer where they are stored in the file server and reports are generated in the office. Data on the reports is checked against information on the lab card before reports are mailed. Billing is conducted once a month using a billing program which gathers information on individual customers and prints an invoice listing, date of sample receipt, test number, lot number, kind of seed, tests requested, test charges, past due and total amount due. Incoming telephone calls requesting information on completed tests or tests in progress are handled in the office by accessing the file server which provides the necessary information.

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[1] Paper presented at the Western Forest Nursery Council Meeting, Olympia, WA, August 12-15, 1986.

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Key data stored upon sample entry includes: the assigned laboratory number, kind of seed, customer sending the seed, lot number, size of lot, seed zone, elevation, and tests requested.

Record and system security is accomplished by two file servers, one of which serves as a backup in event of failure of the main server. File servers are protected from loss of power by an uninterruptible power supply unit (UPS). Data that cannot be held in the file server because of lack of space is archived to tape.

BENEFITS

The computer system just described results in more uniform reports, which are generated faster and contain fewer errors. This results in less fatigue to office personnel, has resulted in less staff and frees them to concentrate on other jobs. Telephone inquiries about status of test results are now handled more accurately and quickly. The monthly billing can now be done in a few hours compared to several days under the old system.

However, the main benefits to the forest industry may relate to the ever expanding database being created and the information it can supply to seedsmen, nurserymen, geneticists, seed technologists, and various researchers.

To maximize use of this database will require planning and close cooperation with all segments of the industry. For instance, if it is deemed desirable to include information about seed vigor on seed germination reports, lot numbers will have to be standardized to insure that vigor results can be sorted by as many factors as possible (i.e. seed kind, seed zone, elevation, year of collection, etc.). The areas described below are examples of how information in the database can be used.

Germination

Seed Vigor

Seed vigor is an indicator of seed quality used for many species. It is particularly useful whenever rapid, uniform emergence is desired, which is certainly the case with the production of conifer seedlings.

Germination values, described by Czabator (1962), combine speed of germination and completeness of germination and can be used to evaluate seed vigor. Currently, germination reports issued by the OSU Seed Laboratory provide all the information needed for calculating germination values (also called germination rates or germination rate indexes). These values could easily be included on the germination report.

For them to be meaningful, however, would require: 1) the development of germination values for each species (i.e. Douglas fir, Ponderosa pine, etc.); 2) controlled field plantings of the same seed lots tested for vigor to correlate laboratory and field results; 3) a grouping of germination values into high, medium, and low vigor classifications; and, 4) sufficient testing over several years, seed zones, elevations, etc. to validate conclusions.

Quality Guidelines

By analyzing germination data, categories of germination could be developed which would be useful in marketing as well as being useful to seedsmen making decisions about seed storage and to nurserymen for determining seed sowing rates.

Again, categories of low, medium, and high germination values could be developed for each species and further broken down by seed zone and elevation.

Research

Data gleaned from the computers could be used by seed technologists to identify species needing research to enhance germination. For instance, the study of the sporadic germination response of White fir (Abies concolor) may be facilitated by utilizing information from the proposed database. Pregermination treatments, such as the length of stratification, could also be better evaluated utilizing the database. Information gained from such studies would be useful to seedsmen, nurserymen, and seed laboratories.

Other Seed Quality Factors

We have spoken about the value of a germination database. However, similar data could be collected on purity, seed moisture content, seed weight, X-ray, and the various quick tests such as tetrazolium and hydrogen peroxide. Correlations between any of these could be run to monitor their validity or to aide in a larger research effort.

CONCLUSIONS

Information about many quality factors is readily available at the Oregon State University Seed Testing Laboratory. With their recent change to computers, this information can be viewed as an expanding database which may have potential uses to many persons associated with the testing of conifer seed. To maximize use of this information, planning should begin now with input from all interested persons.

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Nursery Crop Management Computer System[1]

Valery P. Wyant[2]

Abstract: This paper discusses a computer inventory system Weyerhaeuser uses in all its nursery and greenhouse facilities in the West, South and Canada. It is called the Nursery Crop Management computer system. It provides automated support for many of the crop inventory procedures used to manage our crops. The computer system provides management with control and information relating to the quantity and characteristics of nursery and greenhouse stock.

SYSTEM STRUCTURE

The Nursery Crop Management computer system runs on Wayerhaeuser's Honeywell 6600 computer in Tacoma, Washington. At this time it is being converted to an IBM mainframe and bringing as much as possible down to the IBM PC level. Access to the computer and to the Nursery Crop Management computer system is made by using terminals or IBM PCs. The computer system is comprised of six major components, each designed to support a specific set of functions. These components are:

Time-Share Executive (TS EXEC) allows the operators to interface with all aspects of the computer system. The TS EXEC accepts, edits and interprets all requests and data entered into the system and engages the other components at the request of the operator.

Update component is used to apply (or post) transactions passed to it by the TS EXEC against the database. The Update component also maintains a log of all transactions submitted to the system.

Report component is used to service requests for reports available from the system. Report requests are passed to the Report component to select data from the database and format the desired report.

Fieldsheets component is used to request the creation of inventory fieldsheets.

Inventory component is used to load data onto the sample data files and to run the inventory calculation program.

Data Maintenance component is used to perform a variety of tasks pertaining to technical operation of the system.

Through these components the Nursery Crop Management computer system is capable of many different functions.

FUNCTIONS

Functions available on the Nursery Crop Management System are:

Data Entry function is used to create transactions to be used by the update component.

Report Request function is used to request production reports.

Inventory function is used to enter estimated inventories into the system.

Fieldsheets function is used to request fieldsheets on which to record inventory sample data.

Maintenance function is used to perform various functions that are part of the normal realm of the system.

Reload function is used to reload and restore the update transactions to the database from the history file.

Site function may be used to specify any site or nursery location.

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[1] Paper presented at the 1986 Western Forest Nursery Council Meeting held at Vance Tyee Hotel Tumwater, Washington, August 12-15, 1986.

[2] Valery P. Wyant, Administrative Assistant, Weyerhaeuser Company, Mima Forest Tree Nursery, Olympia, Washington 98502.

List function is used to allow the operator to list the contents of the various transaction, edit table and request files.

Help function is used to list the available options to the last question issued.

Delete function is used to delete update transactions from the update transaction file.

Run function is used to enter a job into the computer for processing.

Print function is used to print the errors or the reports.

JSTS function is used to check the status of a particular job that has been entered into the system.

Done function is used when the operator has completed a session.

Another important part of the Nursery Crop Management computer system is Tables.

TABLES

Tables are used by the system to cross check the operators input to see if the input is valid. They are lists of valid codes used within the Nursery Crop Management computer system.

Customer is a list of the current customer codes and names.

Gcustomer is a list of the group customer codes and names.

Facility is a list of valid facility codes and names.

Gfacility is a list of valid group facility codes.

Storage is a list of storage facility codes and names.

Gstorage is a list of group storage facility codes.

Zone is a list of valid zone codes.

Species is a list of species codes and names.

Treatment is a list of treatment codes and charges.

Class is a list of valid class codes.

Ncustomer is a list of customer names and addresses.

When Ncustomer table is listed, the operator will have the option of creating mailing labels for those customers on the file.

Components, functions and tables are the inner workings of Nursery Crop Management computer system. To utilize these the system must be updated.

UPDATING DATABASE

The update process is logically divided into three steps which must occur in sequence for each update.

Data Entry (DATA) - The first step in updating the database is to enter the transactions to perform the activities desired. This is done by answering the queries and entering data for the appropriate transactions. These transaction types are:

Bareroot Bed Description - add, modify, delete
Plug Bed Description - add, modify, delete
Reference Number - add, modify, delete
Order Revision - surplus, release, modify, transfer
Current Order Modify - class, outplant, amount
Sowing / Transplant - bare, plug, delete
Inventory - user, modify, delete
Stock Order - add, modify, delete
Lifting - add, modify, delete
Storage / Packing - add, modify, delete
Stock Transfer - add, modify, delete
Shipping - add, modify, delete
Crop Book Comments - add, delete
Destroy Stock - in-storage, in-ground, add, modify
Transplant - add, modify, delete

Depending on what you want to achieve, you can add, modify, or delete with any of these transactions.

This simply records the transactions on a file. They are not actually loaded to the database until the update program is RUN.

Program Execution (RUN) - Once all transactions have been entered, the update progam must be run. This program will check the transactions for errors and post the good ones to the database.

Error Checking (PRINT) - To determine if the transactions entered were accepted by the system, the Error and Control Report must be listed. This report lists the transactions in which an error was found during processing.

The report will then list all transactions, wrong and right, and a summary total.

Operators must be certain that all three steps, data entry, program execution and error checking, are performed when updating the database. Failure to do so may mean lost or incorrect data stored on the database.

Whenever the update component is correct and has the data you want, you may request any report you need.

REQUESTING REPORTS

The report process is also logically divided into three parts which must be done in sequence.

Report Request (REPORT) - The first step in obtaining reports is to enter the information to select the reports desired. This is done by answering the queries and entering requests for the appropriate reports. This procedure simply records the requests on a file. Many report types available are:

Block/Bay - facility, block, crop
Crop Book - lifting/sowing, facility, crop, reference #, date
Production Summary - many assorted options
Customer Inventory - facility, customer, type of stock (transplant, outplant, both)
Stock Order Status - facility, customer, status, type, sort sequence
Storage Facility Inventory - facility
Customer (Region) Seedling Inventory - facility, customer, outplant year
Shipment Summary Report - facility, customer, from date, to date, sort sequence

Depending on what you want to see, there are many different ways to sort these reports. Most can be sorted by facility, crop, customer or reference number.

Program Execution (RUN) - Once all requests have been entered, the report program must be run. This program will check the requests for errors and compile the required reports.

Report Printing (PRINT) - Once the report program is complete, the reports are available to be printed.

DIRECTING OUTPUT

When a job has been completed there are two options of where to print, at the facility or at Tacoma.

Another feature of Nursery Crop Management computer system is the seedling inventory component.

SEEDLING INVENTORY

Nursery Crop Management seedling inventory process consists of two major components, Inventory Fieldsheet Creation and Inventory Calculation.

An inventory begins with the request for creation of the inventory fieldsheets. These fieldsheets are produced by the computer and specify the location of each sample point. The inventory crews use the fieldsheets to locate the sample plots and to record the seedling counts. As the inventory progresses, the operator enters the sample data from the completed fieldsheets onto a data file. When all the data has been entered, the inventory calculation program is run. This program calculates the seedling numbers and stores the information on the database.

SYSTEM MAINTENANCE

The system maintenance process is to aid the maintenance and operations staff in performing functions that are not done during normal field processing. Within the systems maintenance component are the functions of History File Update, File Reorganization, Database Listing, Locking/Unlocking System and Database Recovery.

CONCLUSION

With Nursery Crop Management computer system Weyerhaeuser has been able to keep track of hundreds of millions of seedlings at a dozen different locations. All information is easily accessible to the facility or management at any time.

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Using the HP71 Hand-Held Computer for Seedling Inventory[1]

Douglas A. Bluhm[2]

The J. H. Stone Nursery has used a Hewlett-Packard hand held computer since 1985 for data collection during seedling inventory. The use of the HP71B has resulted in improved inventory accuracy, better information handling, and cost savings.

INTRODUCTION

Each nursery has its own method for seedling inventory, but all nurseries have the same need to collect this data for evaluation and reporting. Until 1985 the J. H. Stone Nursery recorded inventory data on paper forms and then transferred the information manually into our computer system. This method was time consuming, allowed for entry errors, was costly, and did not provide timely access to the inventory data. From the beginning of operations at Stone Nursery, we identified the need for a field data recorder to assist the inventory process. In 1984, nursery personnel with assistance from Randy Lunceford of the Deschutes National Forest tested and evaluated the Hewlett-Packard HP71 Hand Held Computer. We found this computer satisfactorily met the requirements for seedling inventory; we embarked upon a process to develop an inventory program and operating proceedures for the HP71.

EQUIPMENT

HP71 Hand Held Computer - This is a powerful computer/calculator that is programmable in BASIC language. The standard memory for this computer is a 64K ROM and a 17.5K RAM. Both the ROM and RAM are expandable. The nursery is uses an expanded RAM of 32K. The cost of the HP71 is $350 (GSA contract). The expanded memory module costs $395.

HP-IL Interface Module - The HP Interface Loop allows the HP71 computer to operate with a variety of peripheral devices, such as, printer, cassette recorder, and other computer systems through an RS-232 Interface. The cost of the module is $53 (GSA contract).

HP-IL RS-232 Interface - This device allows the HP71 to "talk" with other computer systems. This permits the transfer of data from the handheld computer to a main computer system for storage and additional processing. The cost is $210 (GSA contract).

Digital Cassette Drive - The cassette drive is a very necessary peripheral device. The mini-cassettes can be used for storing data and programs. The programs can be loaded from the cassette into the HP71. This makes loading of different programs very easy. The cost is $320 (GSA contract).

Thinkjet Printer - We have used the printer primarily for listing and troubleshooting programs. The HP71 has TRACE FLOW and TRACE VARIABLE commands that aid in analyzing program troubles by printing out the program steps or variables. The cost is $350 (GSA contract).

The minimum equipment required to successfully use the HP71 for data collection would be the HP71, the HP-IL

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[1] Paper presented at the Western Forest Nursery Council Meeting, Tumwater, Washington, August 12-15, 1986.

[2] Production Supervisor, J. Herbert Stone Nursery, Central Point, Oregon.

Interface Module, and the RS-232 Interface. The expanded memory may be necessary depending on the amount of data to be collected and the proximity of the collection area to a main computer for data transfer. The cassette drive and printer are very helpful tools, but not essential for field data collection

PROGRAM DEVELOPMENT

Each nursery conducts its inventory differently, as was mentioned above; therefore, there is not A need to discuss the "mechanics" of the inventory program (formulas, statistics, sampling requirements). Great consideration must be given to the abilities of the individuals doing the work. A program that relies on specialized knowledge of the equipment may present problems to the person who hasn't any experience with computers. Designing a program which is inter-active in format can overcome "computer induced trauma". By querying the operator for input, by presenting clear cut choices on the display, by requiring operator confirmation of data input, and by building error traps and escapes into the program, the chance for operator error is reduced.

Once a program is successfully completed and debugged, the inventory crew must be trained in the operation of the computer. A program flow chart is one of the best tools that can be used in any training session. Practice with the equipment under the guidance of accomplished operators is also mandatory. It is much easier to answer questions and to look at operator problems in a classroom setting than in the field with the crew scattered out over ten or twenty acres. During our training sessions "sample inventories" are entered into the computer. The samples are designed to produce specific results which give operators the opportunity to correct errors, escape from mistakes, and see "correct" machine responses. A well designed training program will help insure that the operators perform the inventory quickly and with few errors.

CONCLUSION

The Stone Nursery's experience in using the HP71 for seedling inventory has been a positive one. The following advantages were evident:

1. Paperwork was reduced.
2. Errors were reduced
3. Cost of inventory was reduced
4. The inventory figures were available on a timely basis.
5. The flexibility afforded by the HP-71 allowed modifications to the program during the inventory.

The high cost of the equipment and alterations to previously established proceedures were the only perceived disadvantages to using the HP-71. Since this equipment has only been used for two years we can not assess its durability. There are many types of hand held computers on the market, and regardless of which brand is chosen, a hand held computer can improve the seedling inventory process.

Root Growth Capacity System[1]

Gary R. Hileman[2]

Abstract.--Design of a Root Growth Capacity (RGC) System that has the capability of creating a favorable environment for initiation of root growth. System construction, parts, and labor were done for approximately $5,500. Blueprints are available.

SYSTEM SEQUENCE

Heated water is pumped from the holding tank, through a solenoid controlled valve, a self-cleaning filter, the mist-chamber pressure gauge, and fog-nozzels. The water is collected on the bottom of the mist-chamber and is gravity carried through a screen-plug in the chamber drain hole and gravity carried through a cartridge filter before going back into the holding tank. Water level in the holding tank is controlled by a float valve on a hose from the water source.

HEATER AND PUMP ASSEMBLY

A 1/2 h.p. pump is used to circulate water from the holding tank to the fog-nozzels in the mist-chambers, 45 p.s.i. It runs constantly, bypassing back to the holding tank when not pumping to the mist-chambers. The reason for this is because of the constant on-off cycle of the mist timer. If the pump had to turn on and off so frequently, it would soon burn out. The misting sequence is triggered by a timer that can be set in 5 second intervals every 10 minutes. When triggered, an electric solenoid opens and allows the water to go through a self-cleaning filter into the designated mist-chambers.

ROOT GROWTH CHAMBER

The mist-chamber is a fiberglass tank approximately 8'x2½'x2½'--just the size of a coffin liner. The tank was painted black to eliminate light in the root zone. Tanks were mounted on an angle-iron frame with walkways between the chambers. The clamps that hold the seedlings are made of two pieces of cedar with foam attached to prevent damage to the seedling stems. The hinges are woven nylon strips stapled to the ends of the cedar boards. Each clamp holds 20 seedlings, and each tank holds approximately 300 seedlings.

Blueprints for the entire system are available from the author.

ROOM SPECIFICATIONS

To have year-round capability of the system, the room requires forced-air heating/cooling, adequate lighting, and room-air humidity control. We accomplished this with a propane furnace, air humidifier, swamp cooler, side and roof windows, and four banks of florescent lights. Good insulation helps reduce energy consumption.

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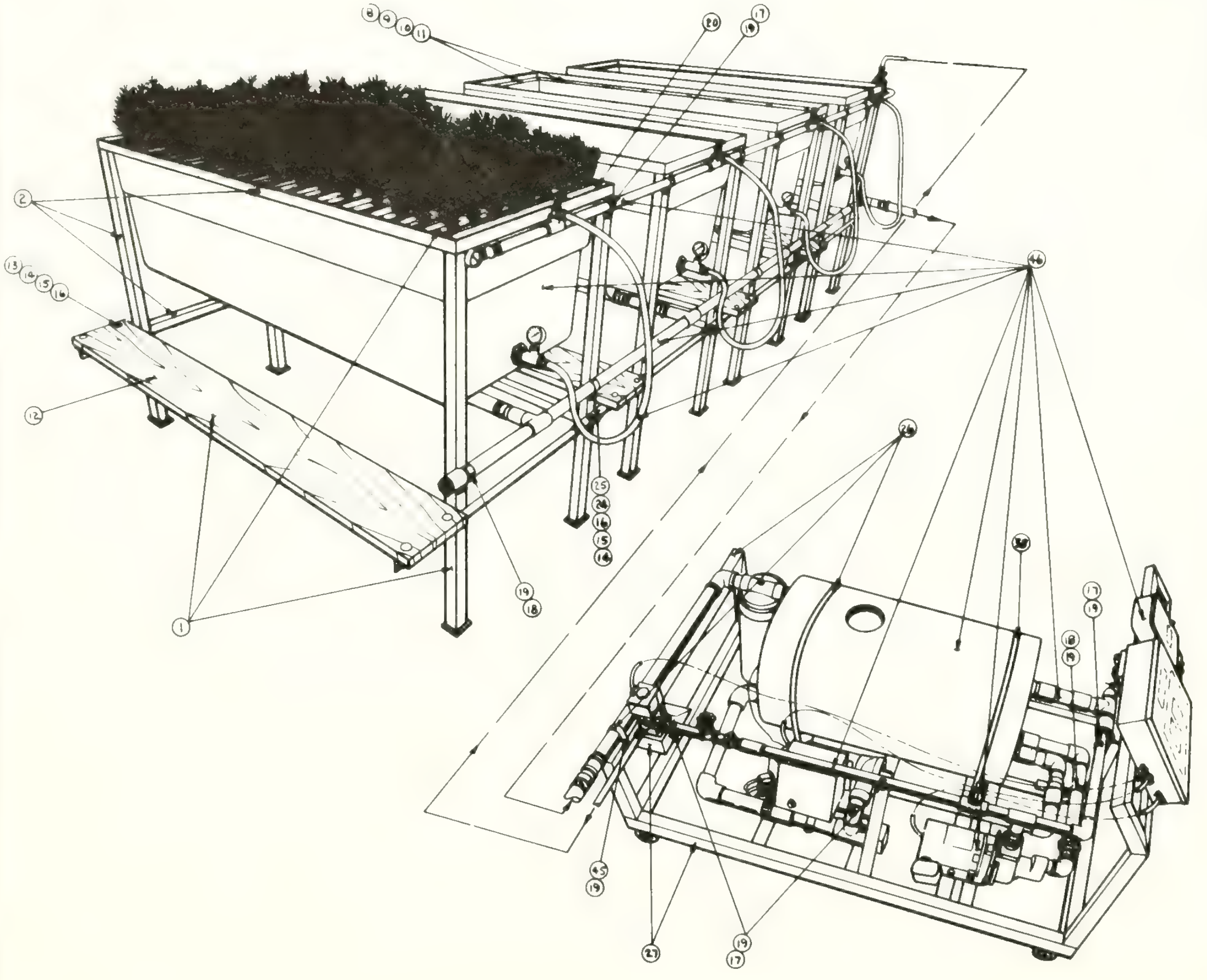
[1] Paper presented at the Western Forest Nursery Council Meeting, Tumwater, WA., August 11-15, 1986

[2] Gary R. Hileman is Welding Worker for Lucky Peak Nursery, U.S.D.A. Forest Service, Boise National Forest, Boise, ID.



MATERIALS LIST

NO	PART NAME	REQD	MATERIAL DESCRIPTION	SHEET
1	SPRAY CHAMBER FRAME	4	PARTS 2 - 25	1,2 & 6
2	SPRAY CHAMBER FR	4	PARTS 3 - 7	2
8	SCREW	[illegible]	1/4-20 x 1 1/2 LG ROUND HEAD MACHINE SCREWS	
9	WASHER	8	1/4 FLAT WASHERS	
10	WASHER (LOCK)	8	1/4 LOCK WASHERS	
11	NUTS	8	1/4-20 HEX HEAD NUTS	
12	WALKWAY	4	2 x 12 x 8'-0" LG DIMENSION LUMBER	
13	BOLTS	16	5/16-18 x 2 1/2 LG ROUND HEAD SQUARE NECK BOLT	
14	WASHER	28	5/16 FLAT WASHERS	
15	WASHER (LOCK)	28	5/16 LOCK WASHERS	
16	NUTS	[illegible]	5/16-18 HEX HEAD NUTS	
17	PIPE CLAMP (1")	10	1 INCH HEAVY DUTY ONE-HOLE JIFFY CLIPS	
			McMASTER-CARR OR EQUAL	
18	PIPE CLAMP (1 1/2")	10	1 1/2 INCH SAME AS ABOVE	
19	SCREW	20	#10 HEX WASHER HEAD ZINC PLATED STL SELF	
			DRILLING METAL SCREWS	
20	SEEDLING HOLDER	[illegible]	PART 21 23	5
24	SPACER BAR	6	PART 24	2
25	BOLT	12	5/16-18 x 1 1/2 LG HEX HEAD BOLT	
26	PUMP/HTR/TK FR ASSY	1	PARTS 27 - 45	3 & 4
27	PUMP/HTR/TK FRAME	1	PARTS 28 - 37	3 & 4
38	TANK HOLDDOWN	2	PARTS 39 - 44	3
45	RETURN LINE STRAP	1	.080 x 3/8 INCH STAINLESS STL BAND-IT BANDS	
			#5422K82 TYPE 216 McMASTER-CARR or equal	
46	PUMP/ELECTRICAL ASSY		PARTS 47 - 86	6

UNLESS OTHERWISE SPECIFIED	DATE	REVISION	BY
TOLERANCES FRACTIONS ± ____ DECIMALS ± ____ ANGLES ± ____	U.S. DEPT OF AGRICULTURE FOREST SERVICE LUCKY PEAK NURSERY BOISE, IDAHO		
DRAWN T COTE DESIGNED B HILEMAN CHECKED APPROVED SCALE NONE DATE [illegible]	TITLE ROOT GROWTH POTENTIAL SYSTEM		
	SHEET 1 OF 6	LPN-7	

Root Regeneration Potential[1]

R. Daniel Dolata[2]

Abstract.--Evaluating root regeneration potential using an intermittent mist chamber is being operationally conducted at the U.S.F.S., Lucky Peak Nursery in Boise, Idaho.

INTRODUCTION

Back in 1970, Dr. E. Stone (1970) gave a paper where he started out chastising foresters and nursery operators for (1) planting "dead trees", and (2) not going beyond the outward physical characteristics of a seedling in their grading of trees. Lucky Peak Nursery has taken one of their first steps to operationally evaluating root regeneration potential of our bareroot nursery stock.

In 1981 Dr. Day piqued our interest in finding a way to economically and efficiently evaluate the root regeneration potential of our seedlings. Are we growing trees that given the proper conditions, will re-establish intimate contact with the soil? Or are they dead? Are we lifting at the right time? Lucky Peak Nursery would like to welcome the advancement of root regeneration potential.

WHAT IS IT? WHAT CAN IT TELL US?

Root regeneration potential, what is it? Day, (1981) recommended this definition; the potential of transplanted or outplanted nursery stock root systems to initiate or elongate new white roots shortly after transplanting or outplanting.

What is it really telling us? We think that in the future we will be better able to help predict survival and establishment of each "source" of seedlings we produce.

How can you do it operationally? (Test the root growth potential that is). First of all we had to look at what we were trying to do. Stone grows his transplants in pots in a warm water bath for twenty eight days then washes the roots off. Day has tried (1) pot bioassay methods, (2) root mist chambers, and (3) root growth boxes. Following MacDonnel's (1981) work we decided to build our Root Growth Capacity System utilizing an intermittent root mist chamber. Now we can evaluate RRP before the stock is shipped.

How large of scale can this be? Is it expandable? Is it faster than the 28 days of Dr. Stone's process? How much did it cost to build? How much does it increase the cost of your stock per thousand? For more information also see paper titled Root Growth Capacity System by Gary Hileman.

HOW DO WE (LPN) DO IT OPERATIONALLY?

Operationally we follow this sort of scenario, (1) during the packing season we have a team doing "THE TESTING" of each source of seedlings as they come into the packing shed. We added to their responsibility that of obtaining a sample of seedlings for testing from each source for RRP evaluation. They are placed into cold storage until the next days batching to go into the RRP system.

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[1] Paper presented at the Western Forest Nursery Council Meeting, Tumwater, WA., August 11-15, 1986

[2] R. Daniel Dolata is the Forester for Lucky Peak Nursery, U.S.D.A., Forest Service, Boise National Forest, Boise, ID.

The next morning the seedlings are taken down to the RRP room to be measured as they are placed into the holding slats. Height, caliper are recorded and any new "white" roots are removed. A sample of ten seedlings from each lot are tested and not placed in adjacent slats.

We've even been able to evaluate seedlings in the summer by using a chamber temperature of 80 degrees Fahrenheit and adding a swamp cooler for cooling and humidity.

Most pines are kept in the chambers for 10 days. This is long enough for the majority of the new growth to occur without the tips turning brown and becomming obscured from the counting and measuring. East side Douglas-fir and Engelmann spruce may take up to twenty eight days before quantifiable growth has taken place.

The work really begins when the seedlings are removed from the chambers. Each replications trees are re-measured for height, caliper, and bud burst, as well as the total number of new roots greater than 1.5 centimeters, the length of the three longest roots in centimeters and the root class of the number of roots less than 1.5 centimeters. See Table 1

At first this was the most time consuming part but with practice it becomes faster. the counting and measuring takes from one minute to five minutes depending on what species and the fibrousness of the root system. As Gary has said it cost us about $5,500 to build this system. To run it cost us last packing season about $1,000 for 4mm trees shipped. That works out to about twenty one cents per thousand seedlings. ($849.00/4,000m seedlings shipped)

Root class originally started out as a way to at least acknowledge that those roots less than 1.5 cm in length could still be of value to the plant in establishing contact with the soil and be faster and more accurate than using a volumetric measurement on the total root system. After a year of trying to average the length of the longest three roots and comming up with some obscure numbers we decided to try and use the same root classes for the longest roots. See Table II

Table II.--Root Class

Root Class	<1.5cm	>1.5cm
0	None	None
1	1-5	1-5
2	6-15	6-15
3	16-30	16-30
4	30+	30+
5	Dead	Dead

To simplify coding and record keeping (we enter this into the U.S.F.S. NMIS Data Base) we record the two classes as RRP 3/4.

Table 1.--Sample data taken after 10 days in Root Mist Chamber

Lot ID	Tree #	Top Height cm	Caliper mm	#New Roots 15cm	Length of 3 longest ---------cm--------			Root Class
LP02850065	1	20	3.5	37	5.0	4.5	4.0	4
	2	18	3.0	40	5.5	4.5	4.5	4
	3	22	3.8	35	5.0	5.0	4.0	3

RECORDS

We realize that this data is important from the product we produce, but more important is how this information relates to the survival through the fifth year. To understand and relate these classes to survival is our hope and project. Lucky Peak Nursery will continue to operationally test each seedlot that is produced in the future. It has taken fifteen years but Lucky Peak is going beyond the outward physical characteristics.

NOTE IN CLOSING: Various authors over the years have tried to quantify these measurements, in many different ways, each a little different than the other. Ours too is unique and I personally feel uneasy in trying to compare my "apples" to anyone elses. A standardized way of expressing the results will be the key to further operationally testing seedlings at the nursery and justifying the cost to the buyer rather than relying on whether or not the minimum morphological grade standards were met.

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Relation Between Cold Hardiness, Root Growth Capacity, and Bud Dormancy in Three Western Conifers[1]

Richard W. Tinus, Karen E. Burr,
Stephen J. Wallner, and Rudy M. King[2]

Abstract.--Ponderosa pine, Douglas-fir, and Engelmann spruce seedlings were greenhouse container grown, then cold acclimated and deacclimated in growth chambers over 19 weeks. Stem cold hardiness, new root length at 14 days, and days to budbreak were measured weekly. During acclimation, root growth capacity had doubled when stem cold hardiness reached -22 °C. During deacclimation, root growth capacity was not lost when two-thirds of maximum cold hardiness was lost. At budbreak, both cold hardiness and root growth capacity were minimum.

INTRODUCTION

The tree nursery industry has long recognized the need for accurate measures of seedling quality (Duryea 1985, Rook 1980). To date, morphological tests predominate, because they are quick and easy to perform, and there is a long history of correlation with survival and growth in the field. Physiological testing at an operational level is still in its infancy, because the tests require more expensive instrumentation and are frequently time-consuming, and in many cases we don't know how to interpret the results. Nevertheless, physiological testing has the prospect of eventually being a far better predictor of field performance than morphological characteristic.

To become established in the field, seedlings must first make root contact with the surrounding soil (Tinus 1974), and it is the new white root tips that are the low resistance pathway for water uptake (Carlson 1986). This is why root growth capacity (RGC) has become an important test and has been found well correlated with field survival and growth (Jenkinson 1980, 1984).

Next, the seedling must grow in height. Meeting chilling requirements for budbreak is rarely a problem with bare-root stock, but can be with container-grown seedlings. More important, budbreak has long been the criterion for judging plantability of stock, yet spring budbreak is the last in a series of physiological changes from winter dormancy to summer growth.

To be a useful management tool, a test has to yield results early enough to change the course of events. Measuring bud dormancy by counting days to budbreak takes much too long. Assessing root growth capacity by the pot test takes 28 days; this can be cut to 7-14 days in the aeroponic mist box (Ritchie 1985, DeWald et al. 1985, Burdett et al. 1983), but probably not less. However, there are tests for cold hardiness that can be done in a matter of minutes to 2 days (Burr et al. 1986, Greer 1983a, 1983b, Pelkonen and Glerum 1985, Colombo et al. 1984, Andrews et al. 1983). Knowing the cold hardiness and the rate of acclimation or deacclimation is valuable for protection of the seedlings, such information could also be used as a quick estimator of bud dormancy and root growth capacity if a good, consistent relation between the three parameters could be found.

The purpose of this study was to find whether such a relation exists. Our research showed that RCG and cold hardiness tests can indicate loss of quality weeks before visible budbreak.

MATERIALS AND METHODS

Ponderosa pine (Pinus ponderosa Laws., Chevelon District, Apache-Sitgreaves National Forest, elev. 2,300 m), Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco, Cloudcroft District, Lincoln National Forest, elev. 2,700 m), and Engelmann spruce (Picea engelmannii (Parry) Engelm., Springerville District, Apache-Sitgreaves National Forest, elev. 3,000 m) were seeded in

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[1] Paper presented at Western Forest Nursery Council Meeting, Tumwater, Wash., August 12-15, 1986.

[2] The authors are, respectively, Principal Plant Physiologist and Plant Physiologist, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Ariz.; Professor of Horticulture, Colorado State University; and Station Biometrician, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

400-ml Rootrainers[2] in peat-vermiculite in October 1985. They were grown in greenhouses at Flagstaff, Ariz., with night temperatures averaging 18-21 °C and day temperatures 23-25 °C until April 1986, when day temperatures began to rise, reaching about 28 °C by June. Daylength was extended to 22 hours with fluorescent light. Other cultural conditions were as recommended by Tinus and McDonald (1979). On June 24, the seedlings were sorted; those of uniform size were placed in four Percival HL-60 growth chambers under 43,000 lux from sodium and multivapor arc lights and kept watered as needed with nutrient solution under a cold acclimation and deacclimation regime (indicated in table 1). All seedlings were of a single population that went through the same succession of stages. At weekly intervals, samples of seedlings were taken for concurrent tests of cold hardiness, root growth capacity, and bud dormancy.

Table 1.--Conditions of cold acclimation and deacclimation

Stage	Duration (weeks)	Day temp. (°C)	Night temp. (°C)	Day length (hours)	Nutrient solution
1	3	20	15	10	Low N, high PK
2	7	10	3	10	Low N, high PK
3	5	5	-3	10	Low N, high PK
4	4	22	22	16	High N

Cold hardiness was measured by a whole-plant freeze test. One book of four seedlings of each species was placed in each of three styrofoam coolers, and the rootballs supported and covered to a depth of 5 cm with dry vermiculite. The coolers were instrumented with thermistor probes in the crowns of the seedlings, the lid wired shut, and the coolers placed in a 650-L household chest freezer. The temperature was lowered rapidly from ambient to 0 °C and at a rate of 3-5 °C per hour thereafter. To reach temperatures below -25 °C, a baking pan was placed in the freezer and filled with liquid nitrogen. The size of pan and degree of insulation controlled the rate of temperature fall. For each species, three temperatures were selected 5 °C apart, which were expected to encompass the LT_{50} of the stem. When a designated styrofoam cooler reached one of these benchmark temperatures, it was removed from the freezer and placed in a refrigerator at +1 °C where it thawed overnight. The seedlings were then removed from the coolers and placed in a warm greenhouse (day 26 °C, night 19 °C, 22-hour day).

After 7 days, the stems were sliced open and the cambium and phloem examined for browning and cell turgor. For each seedling, the proportion of stem that had been killed was estimated. Rates of increasing injury with decreasing temperature were compared across days and species, and data with similar rates was subjectively placed into 5 groups. This pooling of data was necessary because 12 trees for a particular day did not provide adequate information for statistical analysis. For each group, injury in the range 10-90% was regressed against temperatures, and the 50% injury point was estimated by calibration methods (Graybill 1976). The range 10-90% was chosen because the relation between injury and temperature was primarily linear, but nonlinear above and below this range.

At the same time the cold hardiness test was run, eight additional seedlings per species were placed in an aeroponic mist box in a greenhouse (day 26 °C, night 18 °C, ambient day length) to measure root growth capacity. The seedling stems were inserted through holes in plywood strips and held in place with urethane foam plugs. The intact rootballs were exposed to 100% relative humidity at 27 °C maintained by a warm-water intermittent mist. After 14 days, the new white roots that emerged from the rootball were measured (cm ± 1) and counted, and RGC expressed as total new root length per seedling. RGC was measured without damaging the seedlings, which were then returned to the mist box.

The seedlings were left in the mist box until they broke bud. A seedling was considered to have broken bud when 50% of its buds had broken. Days to 50% budbreak were recorded when four of the eight seedlings had broken bud. When this was not observed directly, days to 50% budbreak were calculated by linear interpolation. The observations were plotted against day number during acclimation and deacclimation, with intervals plotted for the interpolated points. The endpoints of the intervals indicate actual measurements.

RESULTS AND DISCUSSION

Budbreak proceeded approximately as expected from previous work (Lavender 1985), but with some differences between species with respect to timing (fig. 1). Engelmann spruce did not break bud at all until day 42, or after 1,176 chilling degree hours below 7 °C. Chilling requirements were fully met by day 71, after 2,800 chilling degree hours. Days to 50% budbreak remained stable at about 21 days until the deacclimation period, during which days to 50% budbreak declined to zero in 21 days.

Douglas-fir did not break bud until day 56, after 1,960 chilling degree hours. Chilling requirements were fully met by day 71 (2,800 hours). Thereafter, days to 50% budbreak remained stable at about 26 days until the deacclimation period, during which days to 50% budbreak declined to zero in about 28 days.

Ponderosa pine did not require any chilling to break bud, and broke bud even at the earliest test dates except at day zero. After 21 days at day

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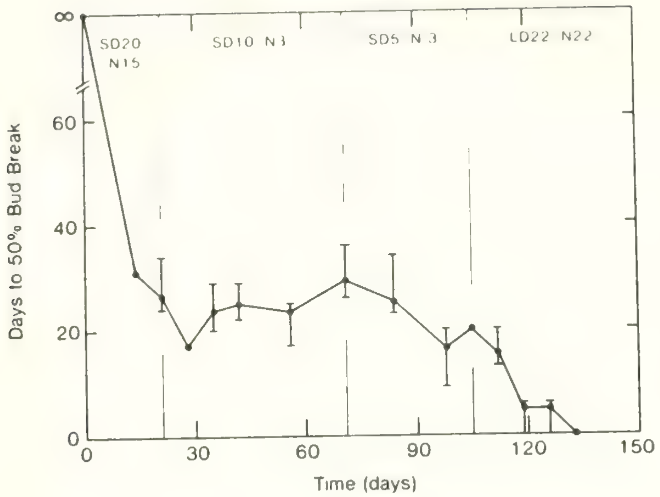
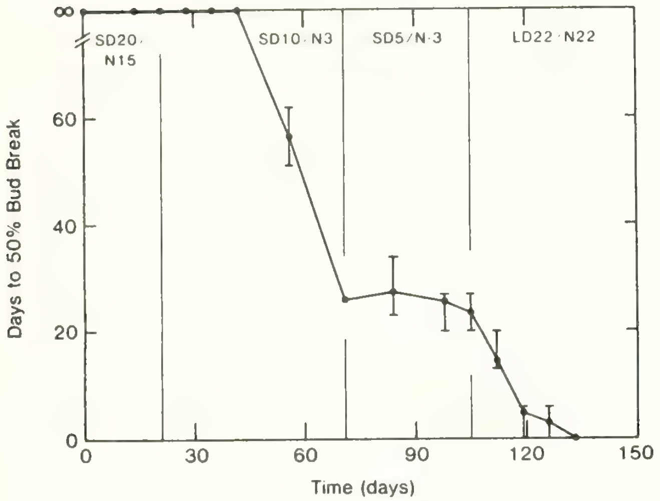
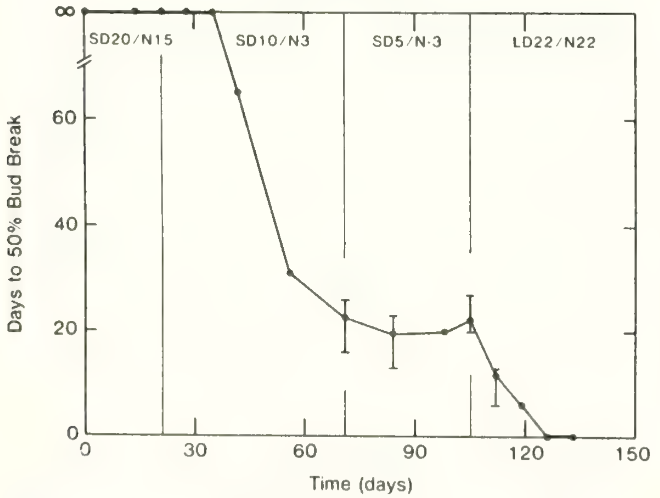
[2] Trade names are used for brevity and specificity and do not imply endorsement by USDA or Colorado State University to the exclusion of other equally suitable products.



A Ponderosa Pine



B. Douglas-fir



C. Engelmann Spruce

Figure 1.--Days to 50% budbreak of (A) ponderosa pine, (B) Douglas-fir, and (C) Engelmann spruce as a function of time. Temperature stages are described in table 1. Plotted intervals indicate interpolated values, the endpoints of the intervals being the actual measurements.

20 °C, night 15 °C, days to 50% budbreak declined to a plateau between 18 and 30 days, but with more variability than Engelmann spruce and Douglas-fir. Days to 50% budbreak declined to zero in about 28 days.

Root growth capacity (fig. 2) of Douglas-fir (fig. 2B) was low (100 cm per seedling) at the beginning of the acclimation period. Two weeks into the second stage of hardening (day 10 °C, night 3 °C) RGC began a rapid rise to a 400 cm peak at day 84 during the third stage of hardening (day 5 °C, night -3 °C). RGC dropped to about 250 cm and then rose to a second peak 1 week into deacclimation. Because of variability, the two peaks separated by a valley may not be distinguishable statistically, but the second peak especially makes sense biologically. Many workers have found an inverse correlation between root and shoot growth, with a particularly strong burst of root growth shortly before budbreak (Riedacker and Arbez 1983, Jenkinson 1980, El Nour and Riedacker 1984). After more than 1 week under deacclimation, RGC declined to a low level (50 cm) at budbreak.

RGC of Engelmann spruce (fig. 2C) was initially low (70 cm); but 2 weeks into the second stage of hardening, RGC rose abruptly to about 230 cm per seedling with a lot of variability. Maximum RGC (320 cm) occurred 1 week into deacclimation; but again, because of variability, the peak may not be statistically distinguishable from the preceding plateau. After the peak, RGC dropped rapidly with the approach of budbreak.

RGC of ponderosa pine (fig. 2A) began at midrange (290 cm) and declined to a low of 100 cm. Two weeks into the second stage of hardening, RGC rose abruptly to over 400 cm, where it remained until the third stage, when RGC again dropped to 300 cm. As with Engelmann spruce and Douglas-fir, a second peak appeared 1 week into deacclimation, followed by a rapid decline as budbreak approached. Again, because of variability, these relations are not clearcut. However, the pattern (fig. 2) is remarkably similar to the one reported by Jenkinson (1980) for bare-root seedlings of the Arizona ecotype (Read 1980, 1983) grown in California nurseries.

Although there are distinct differences between species, the pattern of RGC during cold acclimation and deacclimation showed some very interesting similarities. First, the rise in RGC early in the second stage of hardening occurred at the same time for all three species, although the rise was abrupt in ponderosa pine and Engelmann spruce and more gradual in Douglas-fir. Second, maximum RGC was five to seven times minimum RGC. Third, a second peak (albeit not distinct statistically) occurred 1 week into deacclimation, or 2-3 weeks before budbreak, depending on species. Fourth, RGC declined rapidly as budbreak approached. Although RGC appears to have multiple peaks for each species (fig. 4 below), the variability in the data (fig. 2) is too great to know if the peaks are real.

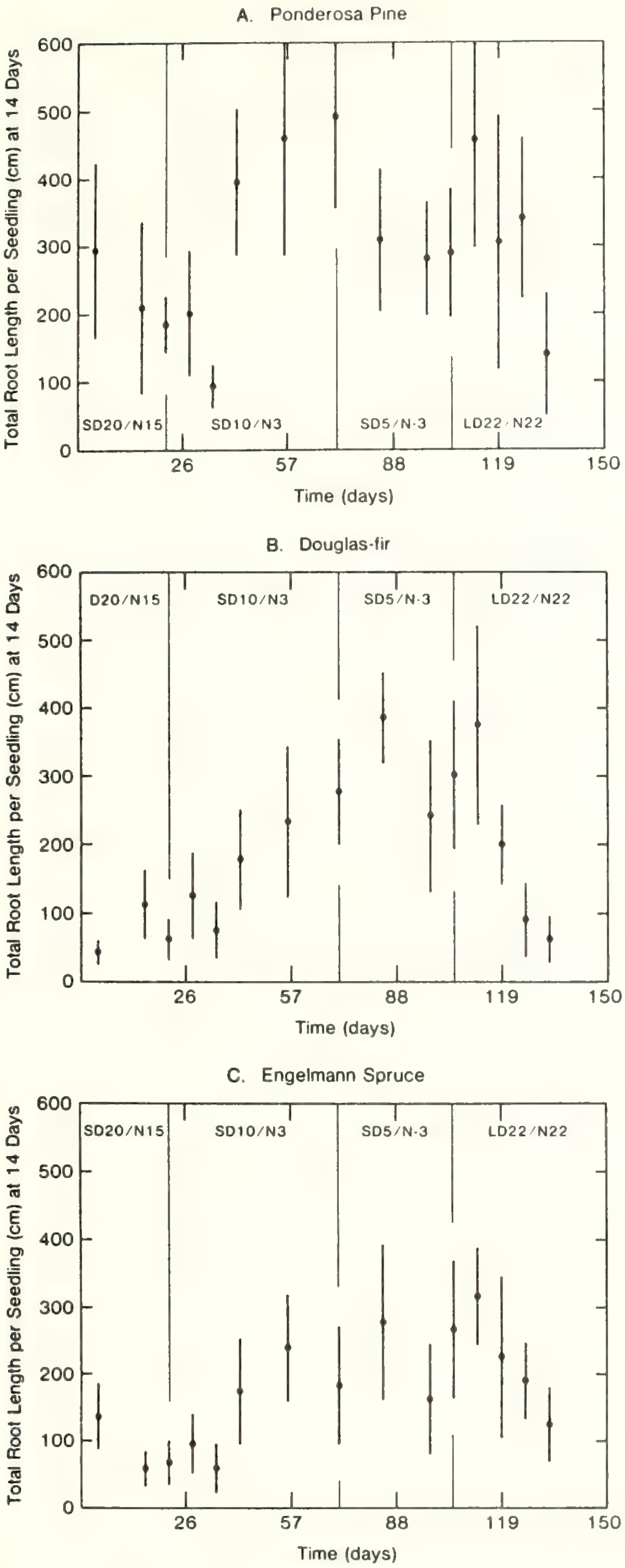


Figure 2.--Root growth capacity as total new root length per seedling at 14 days of (A) ponderosa pine, (B) Douglas-fir, and (C) Engelmann spruce as a function of time. Vertical bars are 95% confidence levels. Temperature stages are described in table 1.

Cold hardiness of each species (fig. 3) was gained and lost as a function of the four successive temperature stages. In the first stage (day 20 °C, night 15 °C, 10-hour day), ponderosa pine (fig. 3A) did not harden, but stem cold hardiness was about -16 °C (LT_{50}). During the second stage, there was no hardening for the first week. Thereafter, hardening proceeded at about 0.4 °C per day until maximum hardiness was reached at about -32 °C on day 71. Upon entering stage 4 (day 22 °C, night 22 °C), deacclimation began immediately and proceeded at about 1 °C per day to a minimum hardiness at about -14 °C.

Douglas-fir stems (fig. 3B) started at minimum hardiness of -11 °C and did not harden during the first temperature stage. During the second stage, there was no significant hardening for 3 weeks. Thereafter, hardening proceeded at about 0.5 °C per day, reaching an LT_{50} of -47 °C by the end of stage 3 (day 105). Gain in hardiness was continuous with no sign of leveling out, as there was in ponderosa pine. Therefore, -47 °C may not represent maximum possible cold hardiness of Douglas-fir stems. Upon entering stage 4, deacclimation began immediately and proceeded at about 2.3 °C per day to -11 °C.

Like ponderosa pine and Douglas-fir, Engelmann spruce (fig. 3C) did not harden during the first stage, nor did it harden during the first 2 weeks of the second stage. Thereafter, Engelmann spruce stems hardened at about 1 °C per day from about -15 °C to -63 °C on day 84. By day 93, 27 days into the third stage, Engelmann spruce was unkillable at -77 °C, which was the low limit of the freezer. Upon entering stage 4, Engelmann spruce deacclimated to -35 °C in 1 week, a rate of at least 6 °C per day. The rate of dehardening declined rapidly thereafter, finally reaching a minimum hardiness of -13 °C.

The principal differences between species seem to be in their rate of hardening and the maximum attainable hardiness, which is much in keeping with the altitude of their native habitat. In Arizona, ponderosa pine grows from 1,800 to 2,700 m, Douglas-fir from 2,400 to 3,000 m, and Engelmann spruce from 2,700 to 3,300 m.

In addition, there are some striking similarities between species. No hardening occurred at warm temperature even with a short day. Based on work on deciduous species, partial hardening might have been expected (Ketchie 1985, George and Burke 1977), but does not seem to occur in conifers (Aronsson 1975) except in high latitude seed origins (Cannell and Sheppard 1982). When the temperature was lowered to day 10 °C, night 3 °C, there was a 1-3 week lag before hardening began. On the other hand, there was no lag in the loss of cold hardiness when deacclimation was initiated, and the rate of deacclimation was two and one-half to six times faster than acclimation. Aronsson (1975) has made similar observations on Scots pine and Norway spruce.

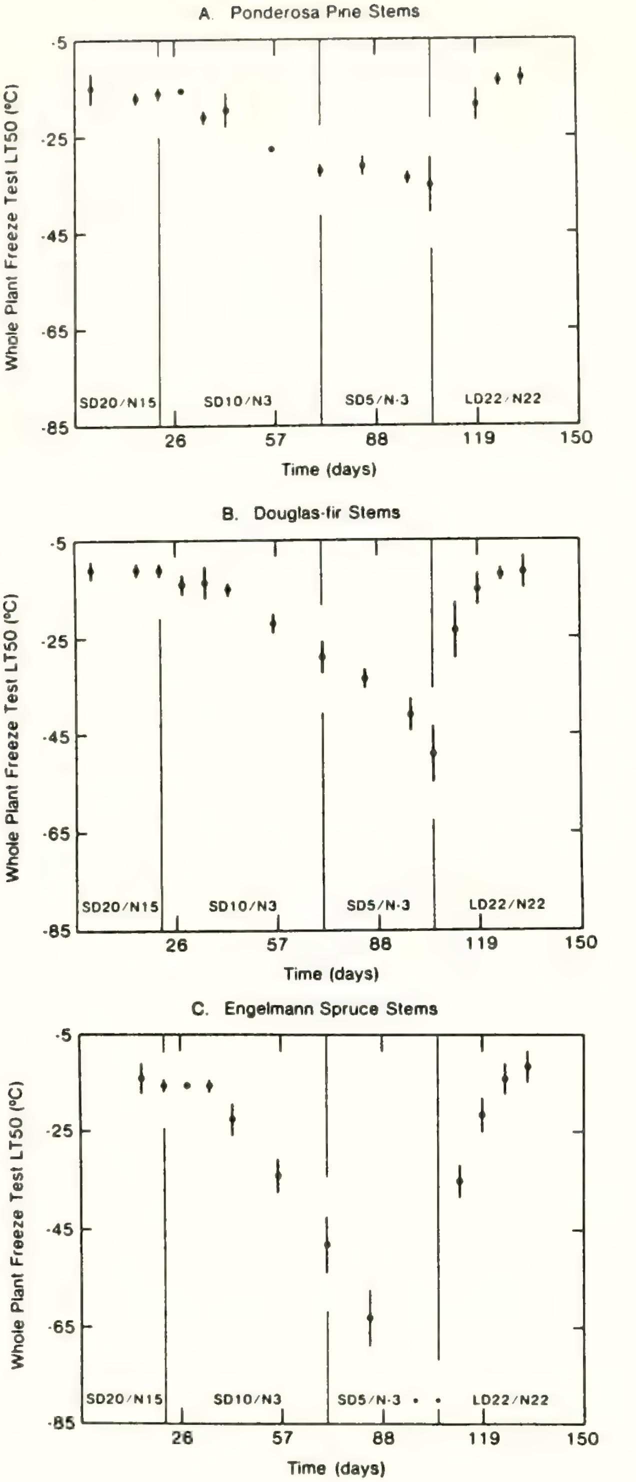


Figure 3.--Stem cold hardiness of (A) ponderosa pine, (B) Douglas-fir, and (C) Engelmann spruce as a function of time. Each LT_{50} and its 95% confidence interval were calculated by calibration methods. The confidence interval is for the mean of 12 observations. Temperature regimes are described in table 1. For day number 112, ponderosa pine was less hardy than the warmest temperature used. On day numbers 98 and 105, Engelmann spruce is indicated at -77 °C, but the stems were not visibly injured.

When cold hardiness, RGC, and bud dormancy are compared, some interesting and possibly useful relations emerge (fig. 4). During acclimation, when stem LT_{50} reached -22 °C, root growth capacity had just doubled. RGC was then on a high plateau in the case of ponderosa pine and Engelmann spruce, and on a continuing rise in the case of Douglas-fir. If this relation were to hold up under further testing, measuring cold hardiness could become a quick way to determine when to begin fall lifting in bare-root nurseries.

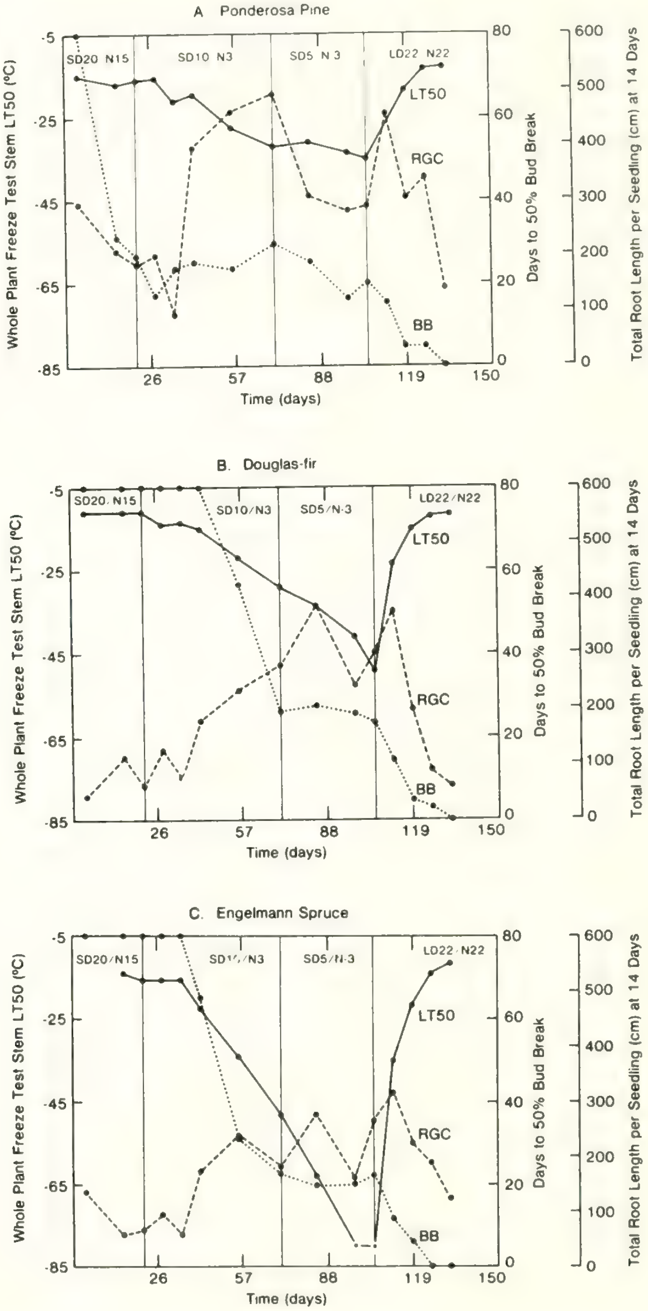


Figure 4.--Composite showing relation between stem cold hardiness (LT_{50}), root growth capacity (RGC), and days to 50% budbreak (BB) as a function of time for (A) ponderosa pine, (B) Douglas-fir, and (C) Engelmann spruce.

Satisfaction of bud chilling requirements occurred at a level of cold hardiness that varied with species: in ponderosa pine -15 °C (no hardening), Douglas-fir -29 °C, and Engelmann spruce -48 °C. This relation may be species- and ecotype-specific, further testing will be required to substantiate this. However, some relation between cold hardiness and bud dormancy is likely as evidenced by the successful use of chilling degree hours to predict bud dormancy in many species (Cannell and Smith 1983, Owens et al. 1977).

During deacclimation, the putative second peak in RGC coincided with a two-thirds loss of stem cold hardiness and one-third of the time toward budbreak from the plateau representing days to budbreak after the chilling requirements were met. This relation could be very useful for determining planting stock quality in the early spring by measuring cold hardiness. By the time 50% budbreak occurred, both RGC and cold hardiness were at their minimum. It is therefore crucial to know the physiological condition of the seedling weeks and even months before 50% budbreak (Lavender 1985).

For ponderosa pine, requirements for budbreak were met about 2 weeks before the precipitous rise in RGC, but in Douglas-fir and Engelmann spruce meeting of bud chilling requirements occurred close to the first peak in RGC. For all three species days to 50% budbreak declined steadily from the beginning of deacclimation, whereas RGC appears to peak and then decline. A pulse of root growth prior to budbreak has been observed in many species (Ritchie and Dunlap 1980).

In this experiment, temperatures were selected for rapid deacclimation. Under less favorable conditions deacclimation would be slower, but the same sequence of events would probably occur. Whether the observed relations between cold hardiness, RGC, and budbreak will be the same under different conditions remains to be tested.

CONCLUSION

Relationships between cold hardiness, RGC, and bud dormancy have been found that support a hypothesis by Ritchie (1985) that such relations exist. At present, it is uncertain how far these results can be generalized. Other ecotypes of ponderosa pine (Jenkinson 1980, Read 1983) and Douglas-fir (Jenkinson 1984) are known to behave differently in many ways. Less is known about Engelmann spruce. Furthermore, these relations were observed under a single set of temperature and photoperiod conditions. Therefore, it would be a mistake to apply them immediately without further testing.

These results suggest cold hardiness testing could be a promising avenue for a quick estimate of RGC and bud dormancy. The whole-plant freeze test is not particularly fast, as it takes 7 days and sometimes longer, but faster tests are becoming available (Burr et al. 1986). It also appears that meaningful information from an RGC test may not be obtainable in less than 14 days (Burr, Tinus, and Wallner, unpublished data), and certainly not in less than 7 days (Burdett et al. 1983).

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Comparison of Four Cold Hardiness Tests on Three Western Conifers[1]

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Abstract.--Container-grown ponderosa pine, Douglas-fir, and Engelmann spruce seedlings were cold acclimated and deacclimated in growth chambers over 19 weeks. A whole-plant freeze test and three tissue tests were performed weekly. The whole-plant freeze test provided results in 7 days and indicated differences in cold hardiness between stems, buds, and needles. Results from a freeze-induced electrolyte leakage test and differential thermal analysis were available in 2 days and 1 hour, respectively. Both tests were good predictors of tissue cold hardiness when calibrated against the whole-plant freeze test. Ethylene and ethane evolution were poor predictors of the development of cold hardiness.

INTRODUCTION

The ability to measure cold hardiness is necessary for successful production and establishment of high-quality greenhouse and field-grown tree seedlings (Glerum 1985, Warrington and Rook 1980). It provides an essential tool for developing optimum greenhouse hardening regimes and for determining the timing of removal of stock from greenhouse to storage or field environments. It provides critical information for sound decisions regarding the timing of lifting, storage and handling, and outplanting of bareroot stock. Knowledge of cold hardiness can also substantially reduce losses from late spring and early fall frosts by establishing the need for protective measures.

The primary method used to assess seedling cold hardiness is the whole-plant freeze test (Ritchie 1984). Though the test is highly reliable, it is time-consuming and the results are not available for at least 7 to 14 days, which is not as soon as usually needed. There are, however, physiological parameters which can be conveniently measured and utilized as tissue tests for cold hardiness that can provide results within 1 to 2 days, or as soon as 1 hour, depending on the test. If a consistent relationship exists between the results of the whole-plant freeze test and one or more tissue tests, seedling cold hardiness could be measured quickly. The reliability of the results from a tissue test would then depend on the calibration, or adjustment, of the tissue test results to match the whole-plant freeze test results.

This paper describes our evaluation of three tissue tests: freeze-induced electrolyte leakage, differential thermal analysis, and ethylene and ethane evolution. Each is quick, objective, and non-destructive of whole plants. Each has its strengths and weaknesses, however, and none are universally applicable. The purpose of this study was to assess the usefulness of these three tissue tests for predicting cold hardiness, and to make the first calibrations of the tissue tests against the whole-plant freeze test.

MATERIALS AND METHODS

Ponderosa pine (Pinus ponderosa Laws.), interior Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco), and Engelmann spruce (Picea engelmannii (Parry) Engelm.) were greenhouse container grown, then cold acclimated and deacclimated in growth chambers over a 19-week regime as described by Tinus et al. (1986). At weekly intervals, samples of seedlings were taken for whole-plant freeze tests and root growth capacity and bud dormancy tests. To establish a firm relationship between the whole-plant tests and the three tissue tests, all were done concurrently each week. An upper lateral branch or a pair of fascicles, depending upon the species, was removed from each of 20 trees per species in the weekly sample for use in the tissue tests, and then the seedlings were used for the whole-plant tests.

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Whole-Plant Freeze Test

The procedures for the whole-plant freeze test and subsequent analysis were as described by Tinus et al. (1986). In addition to measuring percent injury to stem tissue in the whole-plant freeze test, percent injury to buds by a count of live and dead buds, and percent injury to needles by visual estimation of browning, were also measured after 7 days to provide a reference for comparison of the three tissues. The 50% injury points for the three tissues were estimated by regression and calibration methods, following pooling of the data by rate of injury across species, days, and tissue types.

Freeze-Induced Electrolyte Leakage

Measurement of electrolyte leakage from stressed tissue to assess viability is a technique developed by Dexter et al. (1930, 1932). When plant tissue is cooled to temperatures that cause injury, cell membranes are disrupted and electrolytes leak out. The greater the injury, the greater the leakage.

Needle segments, 1 cm long, cut at both ends, were prepared from the tissue samples pooled from the 20 trees per species each week. Segments were washed in distilled water and transferred in random groups of 10 to culture tubes containing 0.5 ml distilled water. Three control tubes per species were stoppered and placed in a refrigerated ice-water bath at 1°C. Treatment tubes, 21 per species, were placed in a Forma Scientific[3] methanol bath at -2°C. After 0.5 hour, the water in the treatment tubes was nucleated with a -80°C wire and the tubes were stoppered. The methanol bath was then cooled at the rate of 5°C per hour. At each of seven test temperatures, selected to span 0 to 100% injury, three treatment tubes per species were removed to thaw in the ice-water bath. After all the tubes were removed from the methanol bath and thawed, 3 mls of distilled water were added to each of the 24 tubes per species and all tubes were stoppered and placed in a 100 rpm shaker at 24°C for 20 hours incubation. Conductivity of the solution in each tube was measured after incubation, and the tubes were then placed in a boiling water bath for 10 minutes to induce complete tissue injury. Conductivity was remeasured after an additional 20 hours incubation in the shaker.

Test results, which were available in 2 days, were reported as percent index of injury (I), calculated by the formula

$$I = 1 - \frac{1-(T_1/T_2)}{1-(C_1/C_2)} \times 100$$

where T_1 and T_2 are the conductivity of the treatment solution before and after boiling, respectively, and C_1 and C_2 are the conductivity of the control solution before and after boiling, respectively (Flint et al. 1967). The formula adjusts the leakage resulting from the low-temperature stress for the leakage from unstressed controls and for the total leakage possible with complete injury of the individual samples of needle segments. The greater the index of injury, the less the cold hardiness at a test temperature.

A weekly data set consisted of 21 observations (three replicates at seven temperatures) for each species. A modified Gauss sigmoid model (Grosenbaugh 1965) was fitted to each set of 21 points (except Engelmann spruce data from days 84, 98, and 105 where linear regression was used) such that

$$I = b_1(1-b_2e^{-b_3t^{b_4}}),$$

where t represents temperature. Temperatures at various index of injury levels were estimated by inverting these models.

Differential Thermal Analysis

The cold hardiness of some tree species is related to a capacity for supercooling, or the cooling of water below the freezing point without ice formation (Burke et al. 1976). The extent of supercooling can be measured by differential thermal analysis. The profile of a cold-hardened bud that supercools (Burr et al. 1986) has two peaks or exotherms representing heat released by the freezing of water within the bud. The first exotherm represents freezing of extracellular water at approximately -6°C, which generally causes no injury to the bud. The second, or low-temperature, exotherm represents freezing of deep supercooled intracellular water and is associated with lethal injury (Sakai 1978). The temperatures at which low-temperature exotherms occur have been correlated with bud acclimation and deacclimation to cold (Tinus et al. 1985). This test can be used with members of many gymnosperm and angiosperm genera such as Abies, Acer, Carya, Fraxinus, Gleditsia, Juniperus, Larix, Picea, Pseudotsuga, Quercus, Tsuga, and Ulmus (Becwar 1980, George et al. 1974, Sakai 1978, 1979). In non-supercooling genera such as Pinus, however, the differential thermal analysis profile is of no diagnostic value because there is no low-temperature exotherm.

Nine well-developed buds of both Douglas-fir and Engelmann spruce were randomly selected each week from the pooled tissue samples for differential thermal analysis. Buds were excised from the stem tissue below the base or crown of the bud to ensure the integrity of morphological features promoting supercooling (Sakai 1979). The cut surface of an excised bud was wetted with distilled water and dipped in a powdered synthetic mica nucleator to reduce supercooling of extracellular water. The bud was then placed in a small cylinder of aluminum foil. The foil cylinder was crimped around a copper-constantan differential thermocouple to insure contact between the thermocouple and bud. A similar foil cylinder without a bud was placed around a reference thermocouple. Several differential thermocouples and the reference were individually covered with small plastic centrifuge tubes and then placed in an aluminum block, which provided uniform cooling. The aluminum block, wrapped with heat tape to regulate temperature, was cooled in a -80°C freezer at 1°C per minute. The cooling rate was automatically controlled by a microprocessor-based controller connected to a variable transformer. Cooling of the block and freezing of water within the buds were documented by wiring the thermocouples through amplifiers and into strip chart recorders.

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[3] Trade names are used for brevity and specificity and do not imply endorsement by USDA or Colorado State University to the exclusion of other equally suitable products.

The aluminum block could be fitted with buds, assembled, cooled, and the data extracted from the strip charts within 1 hour. Mean low-temperature exotherm temperatures with 95% confidence intervals were calculated from each group of nine buds per species each week.

Ethylene and Ethane Evolution

Intact plant tissues synthesize ethylene at different rates during the various developmental stages of the annual growth cycle, with rates highest during active growth periods and lowest during dormancy (Seibel and Fuchigami 1978). Ethylene evolution from excised tissue harvested on different dates has been related in the same manner to the level of vegetative maturity and hardiness in white pine. Ethylene levels were highest in spring during active growth, declined to low levels in fall with vegetative maturity, and were not detectable during winter. Ethylene and ethane evolution have also been found to rise under conditions of stress and strain, respectively (Harber and Fuchigami 1986). The evolution of these two gases was examined not as a viability test, but to explore the hypothesis that the seasonal pattern of evolution of one or both might provide a predictive tool for determining the beginning and ending points of the winter dormancy period, or the starting of acclimation and deacclimation to cold.

Ponderosa pine needle tissue was used for the ethylene and ethane evolution test. Needle tip segments, 2 cm long, were prepared from the tissue samples pooled from the 20 trees each week. Segments were randomly placed into 10, 2 cc gas-tight serum vials, 10 segments per vial. Vials were incubated for 24 hours at 24°C in darkness. Following incubation, a 1 cc gas sample was taken from each vial using a gas-tight syringe, and analyzed for both ethylene and ethane using an Perkin-Elmer 990 gas chromatograph. An activated alumina column was used, and injection port, column, and detector temperatures were 75°C, 50°C, and 150°C, respectively. Preliminary results were available shortly after injections were completed, and final results, reported as ppm/mg dry wt./hour, were available after a 48 hour oven drying period.

Box plots were used to flag outliers in the final data set (Chambers et al. 1983). Six observations that were several, often more than 10, standard deviations from the mean were omitted after each was found to be biologically unreasonable or indicative of problems in experimental procedures. Mean rates of ethylene and ethane evolution with 95% confidence intervals were calculated for each week from the remaining observations.

RESULTS AND DISCUSSION

Whole-Plant Freeze Test

During acclimation and deacclimation, changes in the cold hardiness of needle and bud tissue of the three species followed the same general patterns as stem tissue (fig. 1). Ranking of the tissue types by maximum cold hardiness attained was the same in all three species when tissue differences occurred. Stem tissue achieved the greatest cold hardiness. Needle tissue cold hardiness was similar to that of stems during the first two stages of acclimation and during deacclimation, but did not reach the very hardy levels that stems did. Buds were consistently the least cold hardy of the three tissues in all three species.

The rate of cold hardening in all three tissues of ponderosa pine (fig. 1A) appeared to level out in the third stage of the regime, while in Douglas-fir (fig. 1B), only the hardening of bud and needle tissue stabilized. In Engelmann spruce (fig. 1C), there was no indication that maximum cold hardiness was reached in any of the three tissues.

Needle tissue may be slightly more cold hardy than stem tissue in Douglas-fir and Engelmann spruce during the last 2 weeks of deacclimation, but not in ponderosa pine. The last flush of growth in Douglas-fir was readily distinguishable from earlier growth, before the onset of hardening. During this time, the newest needles were significantly less cold hardy than older needle tissue, at the 95% level of confidence.

The importance of assessing the cold hardiness of the tissue types separately because of differential hardening, such as described here, has been recognized by other researchers (Blake et al. 1979, Timmis 1977). The differential hardening of tissues has a critical impact on the assessment of economic viability of planting stock. For this reason the Industrial Forestry Association has also incorporated separate ratings of needle, bud, and stem injury following freezing tests into their operational cold hardiness testing program (Glerum 1985).

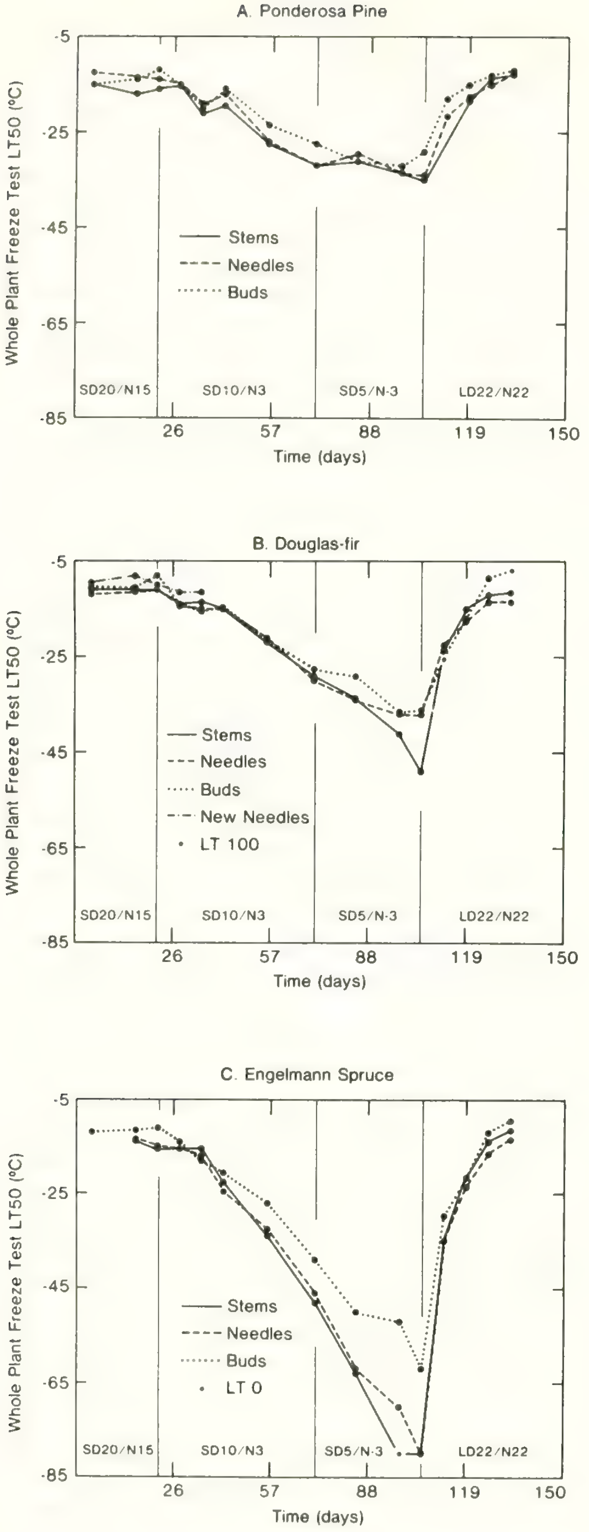


Figure 1.--Stem, bud, and needle cold hardiness of (A) ponderosa pine, (B) Douglas-fir, and (C) Engelmann spruce as a function of time, determined by the whole-plant freeze test. Growth chamber conditions are indicated across the bottom of each graph and are described in Table 1 of Tinus et al. (1986).

Freeze-Induced Electrolyte Leakage

The weekly models of percent index of injury of needle tissue as a function of stress temperature for the three species (fig. 2) are labeled by the day number on which the test was run. Models from days 0, 14, and 21 were from the first stage of acclimation; models from days 28, 35, 42, 56, and 71 were from the second stage; the third stage included models from days 84, 98, and 105; and the remaining models, 112, 119, 126, and 133, were from the deacclimation stage. The range in R^2 for all modified Gauss sigmoid models was .998 to .874. The three linear models, Engelmann spruce days 84, 98, and 105, had R^2 values of .867, .693, and .669, respectively.

Statistical differentiation of the models has not been completed, but preliminary indications are that the test can detect significant differences in cold hardiness of just a few degrees C, at the 95% level of confidence. After little change during the first stage of the regime, there was a gradual progression in cold hardening to day 105, the last data set before deacclimation. The proportionately large loss of cold hardiness during the first week of deacclimation was indicated by a similar change in index of injury from day 105 to 112. Deacclimation then proceeded at a slower rate to day 133 at the end of the 19 weeks. The difference in cold hardiness between new growth and the previous season's growth, after bud break at the end of the 19 weeks, was readily detectable. The new growth, model 133N, was less hardy than the previous season's growth, model 133, in all three species. Once hardened, the previous season's needles did not deharden by day 133 to the level of the new tissue, but retained some residual cold hardiness.

There was also a gradual change in the shape of the models with acclimation and deacclimation. For minimally hardy seedlings (e.g., days 0, 14, 21, and 133), any decline in temperature produced a large increase in injury. As plants became more hardy (e.g., days 84, 98, and 105), a similar decline in temperature produced less injury. This change in sensitivity to declining temperature is an important consideration when assigning critical minimum temperatures to seedlings.

The stress temperatures resulting in 50% index of injury of needles each week were estimated from the data in figure 2 and compared to the whole-plant freeze test temperatures resulting in 50% needle injury (LT$_{50}$) to examine the relationship between the results of the two tests (fig. 3). The freeze-induced electrolyte leakage test followed the changes in cold hardiness as indicated by the whole-plant freeze test quite well for all three species. However, with the exception of the last week of deacclimation, the freeze-induced electrolyte leakage test was a more conservative test because 50% index of injury occurred at a higher temperature than did 50% injury in the whole-plant freeze test. Calibration of the freeze-induced electrolyte leakage test was necessary because of this difference. Preliminary calibration indicated that the

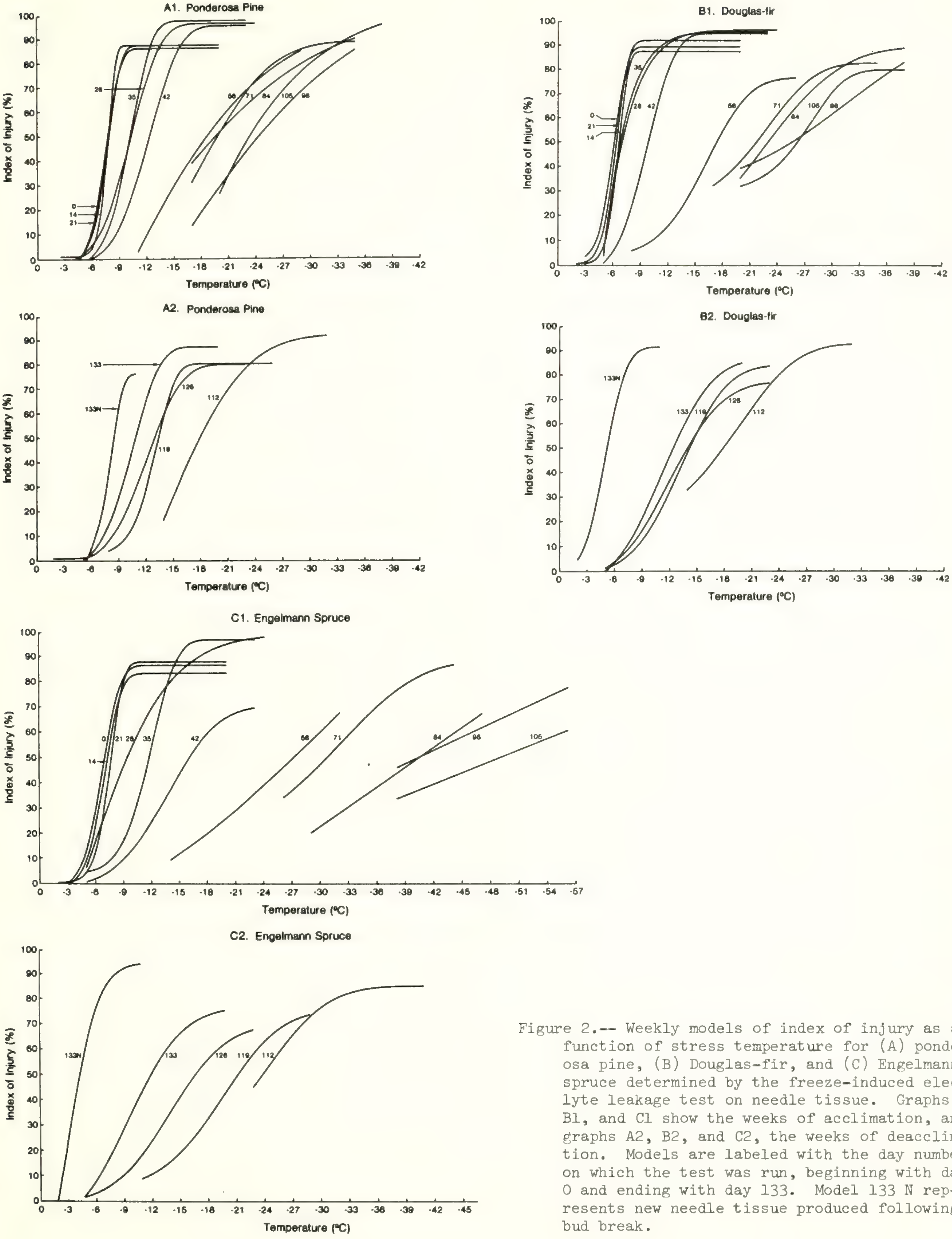


Figure 2.-- Weekly models of index of injury as a function of stress temperature for (A) ponderosa pine, (B) Douglas-fir, and (C) Engelmann spruce determined by the freeze-induced electrolyte leakage test on needle tissue. Graphs A1, B1, and C1 show the weeks of acclimation, and graphs A2, B2, and C2, the weeks of deacclimation. Models are labeled with the day number on which the test was run, beginning with day 0 and ending with day 133. Model 133 N represents new needle tissue produced following bud break.

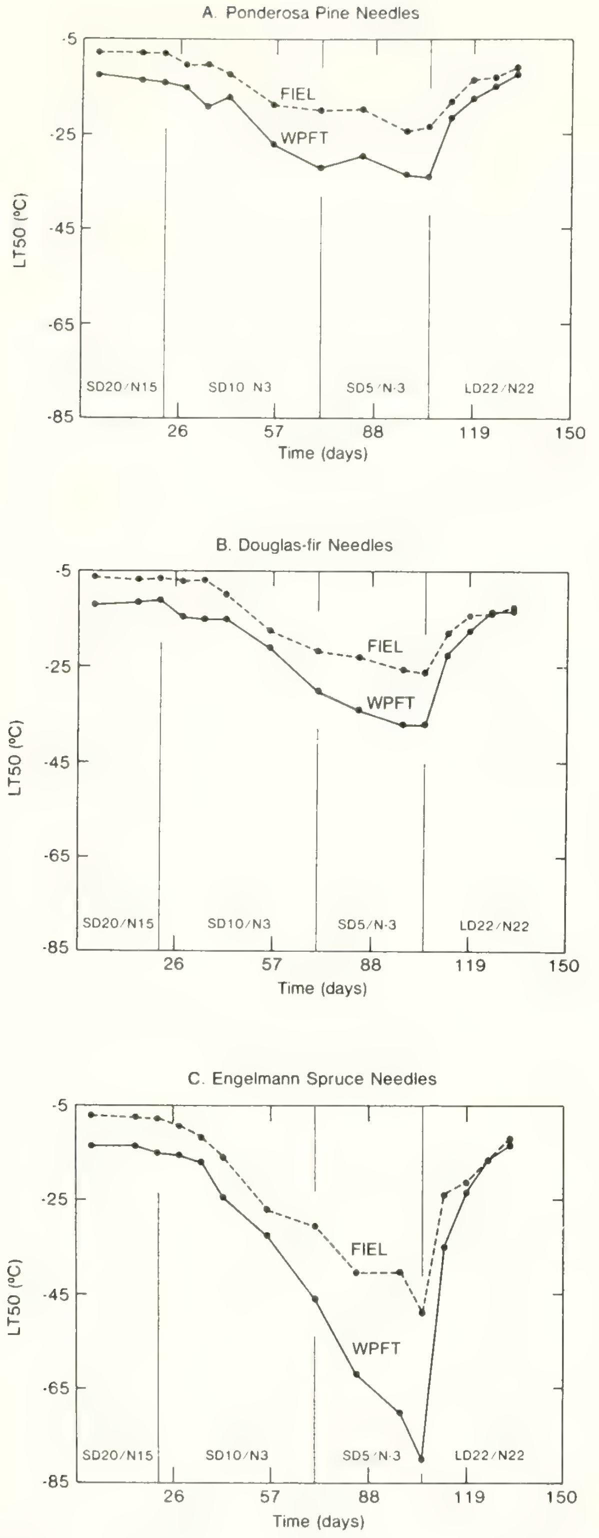


Figure 3.--Temperatures resulting in 50% index of injury to needle tissue in the freeze-induced electrolyte leakage test (FIEL) and 50% needle browning in the whole-plant freeze test (WPFT) as a function of time for (A) ponderosa pine, (B) Douglas-fir, and (C) Engelmann spruce. Growth chamber conditions are indicated across the bottom of each graph and are described in Table 1 of Tinus et al. (1986).

stress temperature resulting in 70 to 90% index of injury in the freeze-induced electrolyte leakage test frequently matched the whole-plant freeze test LT$_{50}$ during acclimation.

This test has been used by a number of workers on a range of coniferous tree species, including Scots pine (Pinus sylvestris)(Aronsson and Eliasson 1970), Monterey pine (Pinus radiata) (Green and Warrington 1978), Douglas-fir (Psuedotsuga menziesii)(van den Driessche 1969, 1976), and black spruce (Picea mariana) and white spruce (Picea glauca)(Colombo et al. 1982). These workers have reported a close relationship between electrolyte leakage from tissue samples and longer term development of visible injury symptoms of intact plants exposed to whole-plant freeze tests. Attempts to predict the lethal temperature of whole plants subjected to freezing tests based on electrolyte leakage of composite tissue samples (e.g. entire stem sections with needles and buds attached) met with variable success. Calibration of electrolyte leakage from a particular tissue to the response of that same tissue in a whole-plant freeze test has not been previously reported.

Differential Thermal Analysis (DTA)

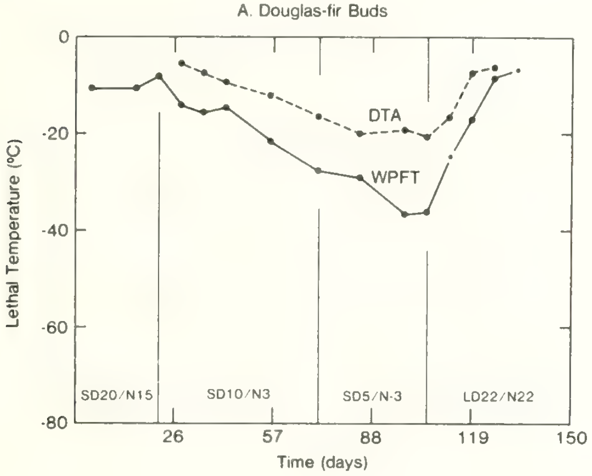
The average weekly low-temperature exotherm temperatures of Douglas-fir and Engelmann spruce buds were compared to the whole-plant freeze test bud LT$_{50}$'s to examine the relationship between the results of these two tests. The DTA test results for both species followed the changes in cold hardiness as indicated by the whole-plant freeze test, but DTA was a consistently more conservative test (fig. 4). DTA data were not available during early acclimation, when bud cold hardiness was warmer than approximately -6°C, because any low-temperature exotherm was masked by the first exotherm.

Based on a sample size of nine, the precision of the low-temperature exotherm means allowed differences during acclimation of ± 2°C to be statistically detected ($p=.95$). Differences of ± 3 to 4°C were significant during deacclimation when the change in cold hardiness was more rapid.

In preliminary calibrations of DTA to the whole-plant freeze test, the average temperature at which the low-temperature exotherm occurred corresponded well with the lowest temperature at which no visible injury to buds occurred, or an LT$_0$, in the whole-plant freeze test (Tinus et al. 1986). Since the buds were the least hardy of the tissues, the average low-temperature exotherm temperature represented the lowest temperature at which there was no injury to the seedling as a whole.

Ethylene and Ethane Evolution

There was a general decline in the evolution of both ethylene and ethane from ponderosa pine needle segments during the 19-week regime (fig. 5). However, the data were so variable that both were poor predictors of seedling or tissue cold hardiness. Some interesting patterns were evident, though. Each time the environmental conditions changed, ethylene evolution was stimulated. The peak in the first stage of acclimation followed the move of the trees from the greenhouse to the growth chambers, and the remaining three peaks occurred at the start of each of the subsequent stages. Greenhouse temperatures averaged approximately 26°C during the day and 20°C at night, with day length extended to 22 hours with florescent light. The change from greenhouse to growth chamber conditions was comparable in magnitude to the other changes. Though a rise in ethylene evolution may be an indicator of environmental change in general for ponderosa pine, the large standard errors of the means made detecting statistically significant differences over time difficult with the sample size of 10 that was used. Differences in ethylene evolution from new growth produced following bud break and the previous season's growth were not statistically significant (fig. 5).


A. Douglas-fir Buds

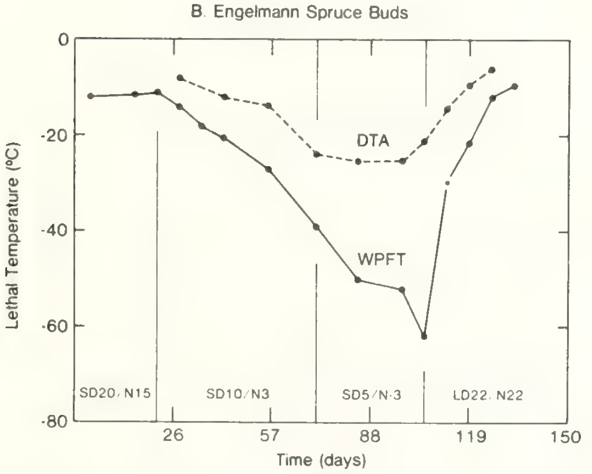

B. Engelmann Spruce Buds

Figure 4.--The average low temperature exotherm temperatures from differential thermal analysis (DTA) of buds and the temperature resulting in 50% bud mortality in the whole plant freeze test (WPFT) as a function of time for (A) Douglas-fir, and (B) Engelmann spruce. Whole-plant freeze test data for Douglas-fir on day 112 represent an LT_{100} at -25°C, and on day 133 represent an LT_{85} at -7°C. Whole-plant freeze test data for Engelmann spruce on day 112 represent an LT_{100} at -30°C. Growth chamber conditions are indicated across the bottom of each graph and are described in Table 1 of Tinus et al. (1986).

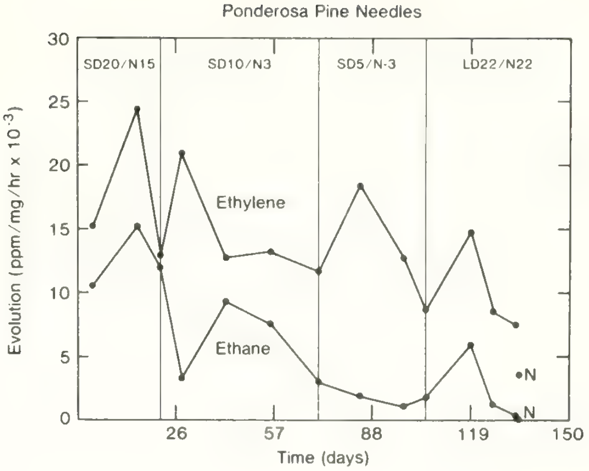

Ponderosa Pine Needles

Figure 5--Ethylene and ethane evolution from ponderosa pine needle segments as a function of time. Data points labeled 'N' represent evolution from new growth produced following bud break. The upper point is ethylene, the lower, ethane. Growth chamber conditions are indicated across the top of the graph and are described in Table 1 of Tinus et al. (1986).

The ethane evolution means were much more precise, and all the departures in the data from the general declining trend were significant at the 95% level of confidence. There was a large drop in ethane evolution as the trees began to cold harden in the second stage, and a large rise in ethane evolution as the trees began deacclimation in the fourth stage. Thus, ethane evolution may be a good indicator of the start of acclimation and deacclimation in ponderosa pine, even though the trees show no visible signs of these turning points in development.

CONCLUSION

The four cold hardiness tests are compared in Table 1. The whole-plant freeze test was most accurate, and could conceivably be used with all species, but the test was cumbersome, destructive of whole plants, and time consuming. Operationally, reliable whole-plant freeze test estimates would also require more plants than used here because of increased viability in field-grown crops.

With the species we tested, the freeze-induced electrolyte leakage test and differential thermal analysis were good, objective predictors of tissue cold hardiness when calibrated to the whole-plant freeze test. They were both precise and thus detected slight changes in cold hardiness. The freeze-induced electrolyte leakage test, though it required two, 20-hour incubation periods, could be tested for use with all conifers, and a great many samples could be measured concurrently with no increase in equipment. It is already being used operationally, with modified methods, because of these advantages (Colombo et al. 1984). The main advantage of differential thermal analysis is that the results can be available within an hour. Buds are also very convenient to sample, require minimal preparation, and exhibit well-defined exotherms. However, the test can only be used with species that deep supercool, and only when reasonably well-developed buds are present. Additionally, differential thermal analysis requires complex equipment which is not readily expandable to handle large sample sizes.

Ethylene and ethane evolution from needle tissue were both poor predictors of cold hardiness in ponderosa pine, but further research may show ethane evolution to be a good indicator of the start of acclimation and deacclimation in this species. The usefulness of this test for assessing the development of cold hardiness in other species has yet to be investigated. The major advantage of such a test is that the tissue sampled requires no exposure to stress temperature treatment.

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Table 1.--Comparison of four cold hardiness tests.

	Predictive ability	Species applicability	Tissue needed	Time required
Whole plant freeze test	excellent	all	whole plant	7-14 days
Freeze induced electrolyte leakage	good	all conifers	needles	2 days
Differential thermal analysis	good	only supercooling	buds	1 hour
Ethylene and ethane evolution	poor	unknown	needles	1 day

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A New, More Efficient Method to Evaluate Root Growth Potential of Planting Stock Using a Root Area Index[1]

W. J. Rietveld[2]

Abstract.--Root growth potential (RGP), the ability of seedlings to promptly and abundantly initiate and elongate new roots after transplanting, is an important and useful attribute of planting stock performance. However, it is generally laborious, tedious, and subjective to measure. A method was developed that employs aeroponic culture of seedlings in a root mist chamber (RMC) and measurement of root growth by changes in root area index (RAI) with a TV camera-based microprocessor area measurement system. The area meter scans each horizontal TV line and sums the segments that are traversed by roots. A high resolution camera was used for accurate area measurement of roots. The method consists of: (1) pre-measuring RAI of individual seedlings, (2) growing seedlings in the RMC for ca. 2 weeks (depending on species), (3) staining new roots to make them visible to the camera, and (4) remeasuring RAI of individual seedlings.

An experiment was conducted to compare xylem water potential (XWP) of seedlings grown in the RMC with that of seedlings grown in pots of medium and seedlings grown in hydroponic culture. XWP, measured with a pressure chamber, of seedlings grown in the RMC was similar to that in potted seedlings, and increased (became less negative) when new roots were initiated. Seedlings in the RMC initiated new roots 1 week sooner than potted seedlings. XWP in hydroponically grown seedlings steadily decreased and very few new roots were present after 20 days.

A second experiment determined the relationship between root growth quantified by difference in RAI and that quantified by direct measurement of new root number and length. A range in RGP was accomplished by placing groups of 10 jack pine 2-0 seedlings in a forced-air oven (40°C, 30% RH) for 0, 10, 20, 30, and 40 min, then growing them in the RMC for 17 days. Root growth of individual seedlings was evaluated by the RAI method and by counting and visually estimating length of all new roots >0.5 cm. Linear regression of individual seedling data revealed r^2 values of 0.88 and 0.90 for predicting number of new roots and length of new roots, respectively, from difference in RAI. Eleven seedlings/person/hour were completed using the visual estimation method compared to 32 seedlings/person/hour using the RAI method.

This research documents the accuracy and productivity of the RAI method. Observer subjectivity is nearly eliminated.

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[1] Paper presented at the Proceedings of the Western Forest Nursery Council

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Monitoring Cold Hardiness of Tree Seedlings by Infrared Thermography[1]

Robert James Laacke[2]
Charles Phillip Weatherspoon[2]
Richard W. Tinus[3]

Abstract.--In this first known attempt, infrared imaging was used to relate foliage temperature to dormancy and degree of cold hardiness in tree seedlings. Species studied were Engelmann spruce, ponderosa pine, and Douglas-fir from northern Arizona. Preliminary results suggest that the dynamic responses of the foliage to changes in light (on/off) are potentially related to degree of cold hardiness. Until these initial results are confirmed in more exhaustive studies, and understood, infrared thermography cannot be recommended as an operational tool for seedling evaluation.

INTRODUCTION

For successful plantation establishment, tree seedlings must be in proper condition to survive the shock of outplanting and to establish a root system in intimate contact with the soil. The condition of a seedling at any time is determined by the interaction of its genetic capacity and the sequence of events to which it is exposed, including the magnitude, timing, and duration of the environmental conditions (Jenkinson and Nelson 1984).

Even if it were possible to know in detail the entire history of the seedling, current understanding of plant physiology would not allow a precise determination of seedling capacities from that history. For this reason there has been a significant amount of effort spent over the last few decades looking for a test or measure of seedling condition that is related to, or predictive of, a response of interest. For the nursery manager, the response of interest could be the capacity to grow new roots at a rate sufficient to ensure seedling survival and rapid early growth following outplanting. The time of interest could be when the seedlings in the nursery enter the physiological condition that makes them capable of being lifted, processed, and outplanted and still retain the capacity to respond favorably in the field. For the regeneration forester, the response of interest may be the same, but the time of interest is later, after everything but planting has become part of the seedling's history. In both cases, once seedling condition is known, decisions can be made and options chosen based on a reasonable anticipation of outcome. To be useful, however, such knowledge must be readily available in time to make the decision or choose the option.

The test applied must meet several criteria. It must be reliable, reasonably easy to use, and not particularly subject to error. In addition, it must be based on principles, processes, or relationships that are sufficiently "known and understood" so that variations in test conditions and results can be interpreted.

This paper reports a study of infrared thermography as a potential means of identifying when tree seedlings change physiological state (e.g., change in dormancy status or frost hardiness level).

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[1] Paper presented at the Western Forest Nursery Council Meeting. [Olympia, Washington, August 12-15, 1986].

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INFRARED THERMOGRAPHY

Using thermal imaging technology currently available commercially, it is possible to create a clear and precise TV-quality image based on surface temperature patterns within a scene. Temperature differences of as little as 0.1°C are apparent, and quantitative data can be extracted from the image.

The major plant factor affecting seedling temperature under a given set of environmental conditions is stomatal conductance (a function of stomatal aperture), because of its effect on transpiration rate and therefore the degree of evaporative cooling. Stomatal conductance is affected by several plant and environmental factors--e.g., plant water stress, light intensity, relative humidity--that usually vary over relatively short time periods. In addition, however, some evidence suggests that stomatal behavior varies over longer, phenology-related periods, perhaps associated with state of dormancy and cold hardiness. Most of this evidence suggests that stomata are more nearly closed (decreased conductance) and respond less to environmental factors including light, when the seedling is dormant (Christersson 1972; Kozlowski 1943; Parker 1963). However, some trees (e.g., coastal Douglas-fir) increase stomatal conductance (stomata more open) during the winter, and their stomata remain open at night (Murphy 1979; Running 1976). If it were possible to isolate seedling temperature patterns attributable to phenology-related changes in stomatal behavior, infrared thermography might be developed into a useful tool for evaluating seedling dormancy or cold hardiness or both.

Current infrared technology is sensitive, easy to use, does not affect the seedling in any way, and produces images that potentially contain far more information than would a single point measurement of temperature or transpiration rate. Preliminary observations of several coniferous species suggested that seedling temperature (as measured by thermography) varies in relation to length of time since beginning of emergence from the last stage of dormancy (Weatherspoon and Laacke 1985).

Thermography could be used for other purposes such as monitoring effectiveness of irrigation systems through effect on relative water stress (Vlcek and King 1983).

Stage 1 3 weeks	Stage 2 7 weeks	Stage 3 5 weeks	Stage 4 4 weeks
10-hr day 20°C day 15°C night	10-hr day 10°C day 3°C night	10-hr day 5°C day -3°C night	16-hr day 22°C day 22°C night

Figure 1.--Environmental conditions during the four stages of the 19-week regime. Stages 1 through 3 were successive steps in hardening, stage 4 was the dehardening time.

METHODS

This study was designed and implemented as an addition to the ongoing work of Dr. Richard Tinus of the Rocky Mountain Forest and Range Experiment Station, USDA Forest Service.

Seedlings of Douglas-fir (Pseudotsuga menziesii var. glauca [Beissn.] Franco), Engelmann spruce (Picea engelmannii Parry ex Engelm.), and ponderosa pine (Pinus ponderosa var. scopulorum Engelm.) were greenhouse grown in 400 ml Rootrainers,[4] one seedling in each of the four compartments of the folded container, or "book." Beginning in June, 1985 they were moved to growth chambers where photoperiod and day/night temperatures were altered in four stages over a period of 19 weeks, first to induce cold hardiness and then to promote dehardening (fig. 1). A full description of the environmental conditions maintained during each stage, as well as the physiological results of the hardening and dehardening regime, are described in papers by Tinus et al. and Burr et al. elsewhere in these proceedings.

Apparent foliage temperatures were measured with an Inframetrics 525 Imaging Radiometer at the time of each scheduled stage change. At each measurement time, infrared images of seedlings were recorded on video tape which, along with appropriate instrument data and verbal notes, permitted later quantification of seedling temperatures.

Seedling temperature is affected not only by stomatal conductance, but also by a number of environmental variables. To try to minimize the effects of these other variables, we made most of the thermographic measurements in a separate "measurement" growth chamber maintained as nearly as possible under constant environmental conditions. Temperature was set at 20°C during both light and dark periods. Relative humidity generally ranged from 25 to 35 percent. During light periods, sodium and mercury vapor lamps provided about 150 $uEs^{-1}m^{-2}$ of PAR (photosynthetically active radiation) at seedling height. This level of radiation permitted near-maximum stomatal conductance in actively-growing, well-watered seedlings, yet minimized temperature differences between shaded and directly irradiated portions of a seedling.

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[4] Tradenames and commercial products and enterprises are named solely for information. No endorsement by the U.S. Department of Agriculture is implied.

Eight seedlings of each species were removed from the conditioning environment at the end of each stage throughout the hardening/dehardening cycle and placed in the measurement chamber. Infrared temperature measurements were begun the day following removal and were continued for 2 days. During this time thermographic measurements were taken through transition periods from lights off to lights on, and from lights on to lights off. Measurement began before light conditions were changed and continued for up to 3 hours. The seedlings were then placed in the root growth capacity test described by Tinus et al. (these proceedings).

For measurements in the chamber, the sensor was mounted on a remotely controlled swivel and the seedlings were arrayed in a semi-circle equidistant from the swivel point. Air temperature in the chamber was monitored in three ways: (1) A dial thermometer was inserted through the wall of the chamber and into the air flow before it passed over the seedlings. Temperature indicated on this thermometer was recorded at the beginning of each sensor scan. (2) A recording hygro-thermograph was placed in the chamber in the center of the semi-circle of trees and below the level of the foliage. Air temperature and relative humidity were recorded continuously on a 7-day chart. (3) Additional temperature references, readable by the infrared sensor, were placed in the chamber to provide a real-time indication of air temperature in the vicinity of the seedling and as a visual reference in reviewing the video tapes. These non-standard temperature references, or "wicks," were wedges of filter paper held by one end in plastic soda straws and displayed as fan-shaped objects close to the foliage of the trees to be measured. One was kept wet by immersing one end in a bottle of distilled water. This was intended to provide, along with the temperature of a similar but dry wick, a reference to relative humidity. Ultimately, only the temperature of the dry, white wicks was used as the thermal reference for air temperature. In this report, all foliage temperatures are described as degrees centigrade above or below air temperature.

During the dehardening stage, supplementary measurements were taken on a table outside the measurement chamber. For the first 2 weeks of the dehardening stage, these measurements were taken daily to monitor anticipated rapid changes in physiological condition of seedlings. For the time required to take the measurements, seedling containers were placed on a rack inside a large 3-sided cloth enclosure open at top and bottom. This was done to measure seedling temperature responses without the forced air flow--unavoidable within the chamber--that tended to mask the effects of stomatal conductance on seedling temperature. A bank of lights--producing 4000 lux of cool, white, fluorescent light--was suspended 60 to 90 cm (2 to 3 ft) above the seedlings. A shielded mercury thermometer was suspended just above the seedling tops. As in the measurement chamber, dark-to-light and light-to-dark transitions were monitored.

When the dehardening stage began, a supply of seedlings of each species was held in conditions of the third stage of hardening (fig. 1). Two books of four seedlings of each species were removed at about 2-day intervals and placed in the dehardening conditions of stage 4 (fig. 1). This provided the opportunity to test seedlings at three different states of dehardening at the same moment and under the same conditions. Measurements were continued daily for 10 days.

RESULTS AND DISCUSSION

Hardening Period

At the end of the greenhouse phase, and before seedlings were placed in stage 1 hardening conditions, foliage/air temperature differences were near zero during dark periods for all species. When lights were turned on, foliage temperatures dropped to between 1° and 2°C below air temperature. In successive light periods no one species was consistently warmer or cooler than the others. The general pattern of temperatures is consistent with the type of stomatal behavior expected in actively growing plants.

At no other time in the 19-week regime did foliage temperatures warm up to air temperature in the dark, even after 16 hours of uninterrupted darkness during dehardening. The time when foliage temperatures returned to air temperature corresponded with the only time in the 19 weeks that fully matured, current-year's foliage, as yet unexposed to hardening conditions, was present.

At the end of the first stage of hardening, differences between species in general foliage temperature appeared. Ponderosa pine and Douglas-fir were similar and both warmer, on the average, than Engelmann spruce. During light-to-dark and dark-to-light transition, ponderosa pine and Douglas-fir foliage temperatures overlapped.

At the end of the second stage of cold hardening, relative temperature of Engelmann spruce fell farther below the other two species. On the first day after removal from the treatment chamber, ponderosa pine was warmer than Douglas-fir. By the second day, ponderosa pine was cooler than Douglas-fir, and Engelmann spruce became even cooler relative to the other two. A possible explanation for the change in relative position of the species is that low soil temperature in the container (residual from the induction treatment) affected ponderosa pine more than Douglas-fir, and the resulting increase in resistance to water uptake and movement reduced the amount available for transpiration and, therefore, increased the tissue temperature. By the second day, sufficient warming could have occured to allow pine to absorb and transport water more easily. This relative difference would be consistent with data on other species that indicate a greater effect of cold soil on low elevation or low latitude sources relative to those from higher elevation or higher latitude (Kozlowski 1943; Kramer and Kozlowski 1979) and with the relative elevations of the sources of all three species.

At the end of the third stage of cold hardening, relative temperatures of the species changed again. At this time Douglas-fir and Engelmann spruce had equivalent temperatures and both were warmer than ponderosa pine.

On the first day after placement in dehardening conditions, the foliage temperatures of all three species were equivalent. However, after 4 weeks in uniformly warm temperatures, Engelmann spruce had again assumed, on the average, a lower temperature than the other species.

It was obvious during the three cold hardening stages that foliage temperature varied from place to place on seedlings of all species. A common situation, especially for Engelmann spruce, was an area of foliage that was distinctly cooler than the rest of the seedling. Occasionally areas would develop that were distinctly warmer than the rest of the seedling. For example, branch tips of Engelmann spruce were occasionally up to a degree warmer than the general foliage. Temperature patterns periodically developed on seedlings with a range of 1.3° to 4.3°C difference between the warm areas and the cool areas.

Dehardening Period

More detailed data were gathered during the dehardening period because it was possible to measure the same seedlings repeatedly over an extended time. During the transition time from maximum to minimum cold hardiness (time of bud break), response of seedlings to light changes varied at different stages of dehardening. By the time the process was complete, seedlings within each species responded very much alike (fig. 2).

If physiologically reactive stomates tend to close in the absence of light, transpiration should be reduced and foliage temperature should increase relative to air temperature when lights are turned off. Until Douglas-fir seedlings had lost an estimated 30% of their acquired cold hardiness, the temperature of the cool areas on the seedlings decreased or remained unchanged relative to air temperature when the lights were turned off. After losing about 30% of the total hardiness gained, temperature of the cool portions of the plant increased in the absence of light.

General temperature response patterns to changes in light (on or off) did not change although differences between foliage and air temperature did change with water availability. Foliage temperatures increased as container medium dried between waterings.

For ponderosa pine, foliage temperatures began to increase relative to air temperature when lights were turned off, after 20% of the maximum attained hardiness was lost. Engelmann spruce, however, never did settle into a stable pattern. Temperatures did generally stop dropping relative to air temperature after about 20% of the maximum cold hardiness was lost. Only after about 75% of the acquired hardiness was lost did the foliage temperature increase relative to air temperature when the lights were turned off.

SUMMARY AND CONCLUSIONS

The study reported here was the first step toward determining applicability of thermal imaging systems in assessing physiological state of seedlings (for example, their status regarding dormancy or cold hardiness). As such, it must be viewed as exploratory. Because the study was opportunistic in the sense that it was added on to another, more intensive study designed to answer different questions, the amount of manipulation was limited. For this reason, and because of restrictions on the randomness of seedling selection (seedlings were

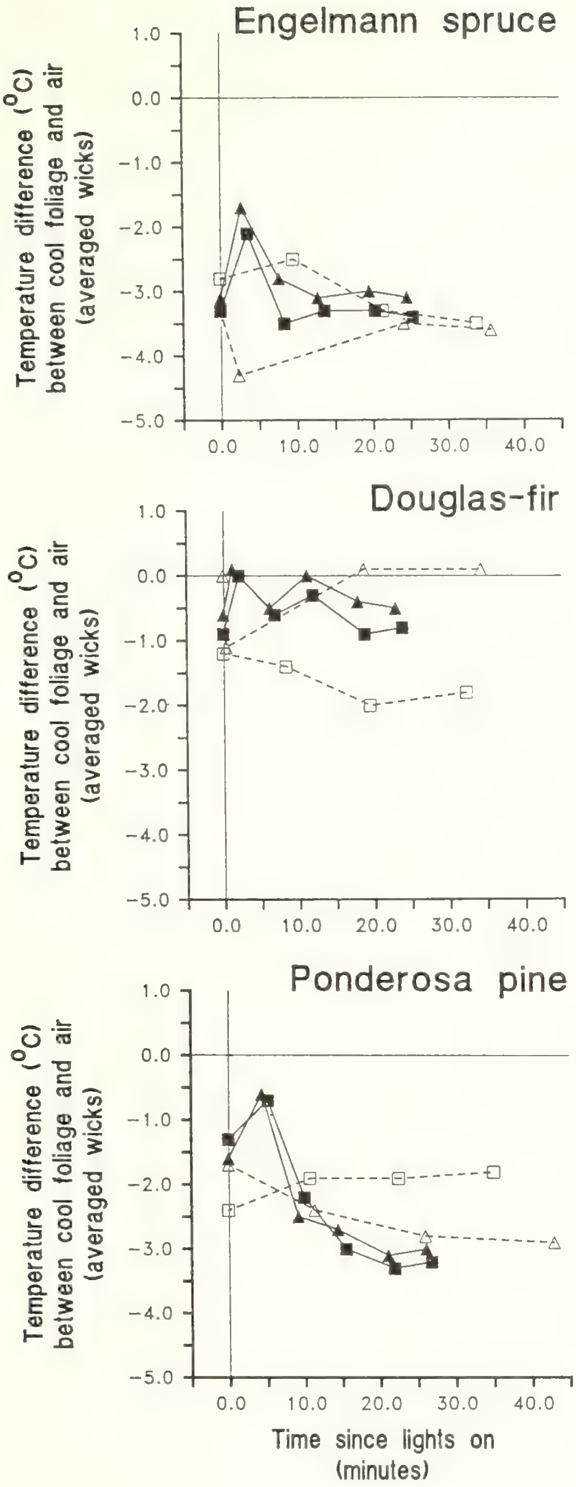

Figure 2.--Temperature response of cool regions on the seedlings during the first hour after turning lights on. Data are average temperatures of seedlings 1-4 at 3 days (open triangles) and 29 days (shaded triangles) and of seedlings 25-28 at 3 days (open boxes) and 22 days (shaded boxes) after removal from stage 3 hardening conditions.

in books of four seedlings each, were limited in number of books, and were measured in the same growth chamber) statistical analysis was limited to description of averages only. Notwithstanding, several responses were observed that could be important to further research:

- Confirmation of the observed change in temperature response with relative degree of cold hardiness during the dehardening period, and demonstration of similar changes during the hardening process, could be the basis of a useful tool.

- The observation that changes in water availability do not change the initial temperature response pattern, but only the actual temperatures achieved, must be carefully verified. If true, a series of potential obstacles to the operational use of thermography (e.g. differing soil water potential, low soil temperatures) are reduced or removed.

- Seedling response to the transition from light to dark is potentially more useful to monitor than is the transition from dark to light.

- The time of most useful response appears to be in the first 20 minutes after a change in light.

- Foliage on a seedling is not all the same temperature, and the cool areas appear to be more useful in defining response patterns than is the general temperature of the seedling.

- Engelmann spruce foliage temperatures were surprisingly low relative to air temperature and dropped as hardiness developed. This observation suggests that stomatal conductance could be high in the winter, a situation similar to coastal Douglas-fir but unexpected in a high elevation continental species.

This study has clearly identified some significant areas for further research and suggests that much could be learned about seedling physiology using thermography. There are tantalizing hints of approaches for use of the method in tracking dormancy or cold hardiness. For example, if the patterns of temperature change following removal of light are verified to be related to cold hardiness state, then an operational test might be developed that would be completed in less than 30 minutes rather than days or even weeks.

For future studies, given the timing of root growth capacity and development of cold hardiness described by Tinus et al. and Burr et al. (these proceedings), it would be desirable to schedule thermographic measurements during the time the seedling physiology is changing rather than at times when growth chamber conditions change.

However, thermography cannot be suggested as a useful tool until some of the responses noted in the study are verified and understood.

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Root Growth Potential in Coastal Container Species: Trends from Operational Testing and Prediction of Outplanting Performance

B.G. Dunsworth[1]

Abstract. One-week root growth potential tests appear adequate for operational go/no go decisions on coastal container and bareroot planting stock. Stress resistance mechanisms related to dormancy intensity and cold hardiness appear to play a more significant role than root growth potential for seedlings with a reasonable ability to produce roots.

INTRODUCTION

Assessments of a seedling's ability to produce roots have been evolving since the work of E.C. Stone in California in the late 1950s. Much of the initial work focused on understanding the progression of root phenology in seedlings, what the root growth stimulus was, and how it might be related to such things as bud dormancy, carbohydrates (current or stored) and outplanting vigor.

The major impediment to using root growth potential assessments as an operational forestry tool was the two-month duration of the test. By the time "poor" seedlots were identified, it was too late to act. A.N. Burdett[2] (1979) developed a rapid test (1 week) and assessment method which made possible operational assessment in white spruce and lodgepole pine. This method was found to be well correlated with outplant survival.

MacMillan Bloedel (MB) had been concerned about plantation performance in coastal conifers for many years prior to the development of Burdett's test in 1979. Most foresters believe many of their plantation failures could have resulted from poor stock quality.

The establishment of a private container nursery in 1979 and confirmation of a number of bareroot plantation failures in 1982 being directly related to low root growth potential, led to MB instituting operational root growth potential monitoring in 1984.

The operational testing was established as the first in a series of steps to:

- eliminate planting stock with a low probability of success prior to shipment
- improve nursery culture to such a point that the probability of producing low vigor planting stock was minimized.

ROOT GROWTH POTENTIAL (RGP) METHODOLOGY

The rapid RGP test[2] has been used as an operational monitoring system by MB in the following fashion:

1. Sampling: Samples (25 trees/seedlot) are taken on a regular basis from time of lift to time of plant.

2. Growing Medium: Seedlings are potted in 20-centimeter diameter pots, 5 seedlings per pot. Medium consists of a 1:1 peat: vermiculite mix maintained at a pH of 4.5.

3. Growing Environment[3]: Pots are kept at field capacity in a controlled environment for one week at:

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[2] Burdett, A.N. 1979. New methods for assessing root growth potential: their value in assessing lodgepole pine stock quality. Can. J. For. Res. 9:63-67.

[3] Recent evidence from the B.C. Ministry of Forests (Dr. W. Binder) suggests that the optimal environment for root expression in most coastal conifers is closer to 22°C/18°C (D/N). Our 1986 operational evidence using both environments confirms this, particularly for species with poor heat tolerance. However, improvement of prediction of outplant success (survival and growth) has yet to be proven.

30°C day temperature 400u einstein light intensity
25°C night temperature 75% relative humidity
16 hr photoperiod

4. Indexing: After one week each seedling is scored for root activity using the index developed by Burdett (1979). These values are averaged to give a single value for each seedlot. The index is as follows:

Indexing Value	Number of New Roots	Indexing Value	Number of New Roots
0	none	4	11-30 >1 cm
1	some, none >1 cm	5	31-100 >1 cm
2	1-3 >1 cm	6	101-300 >1 cm
3	4-10 >1 cm	7	>300 >1 cm

RESULTS OF OPERATIONAL MONITORING AND PREDICTION OF OUTPLANT SURVIVAL

The following graphs illustrate how RGP of operational planting stock is related to operational and research outplant performance during 1984 and 1985. Note: RGP of 1.0 is currently considered the silvicultural soundness level. Plantation survival of 80 percent is the MB, Designed Forest plantation target.

1984/85 Operational Results

The shape of the RGP versus time curve (Fig. 1) illustrates the general case of RGP rising and then falling as planting stock progresses from lift through storage. Our operational evidence suggests that the positioning and shape of this generalized curve for any given season is dependent on species, seedlot, and cultural factors at the nursery level related to dormancy induction and hardiness. Chilling (natural and stored) may play a strong role in controlling RGP levels and timing.

Analysis of operational RGP testing and plantation performance data (Fig. 2) indicates that RGP can be used as a red light/green light tool for survival and that seedlings with some new roots, none >1 centimeter, would be a reasonable cutoff for sound planting stock.

Our ability to accurately predict outplant survival for seedlings exhibiting any number of new roots >1 centimeter is weak. For these seedlings, other physiological processes interact with limiting planting site conditions to influence seedling survival to a much greater degree than RGP.

1985 Common Garden Results

Douglas-fir seedlots were lifted February 15 and either planted or stored for 6 weeks or 21 weeks and planted. Outplantings were established in a non-irrigated, seed orchard field. The site was plowed to facilitate planting; vegetation was

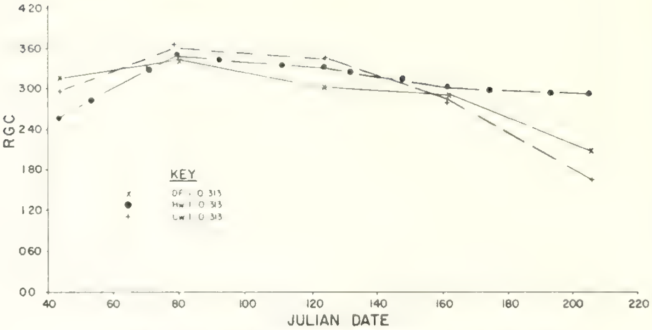

Figure 1 This figure illustrates the progression of root growth capacity in storage for three containerized coastal species Douglas-fir, western hemlock, and western red cedar All seedlings were lifted during the first week of February 1985.

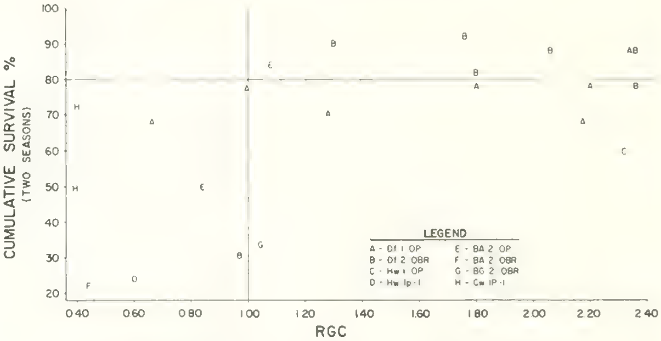

Figure 2. Plantation survival tends to drop rapidly for seedlots with no new roots >1 centimeter in most coastal conifers.

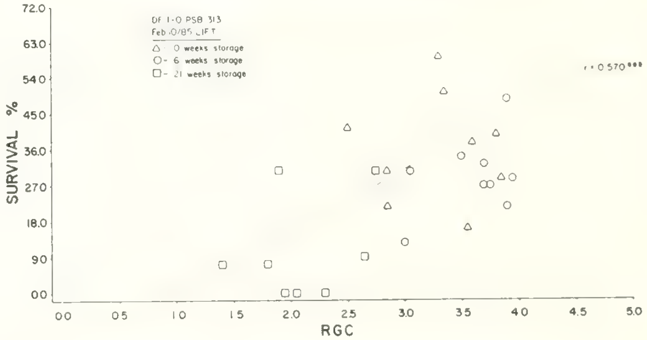

Figure 3 Containerized Douglas-fir seedlings exhibit high survival with high RGC and low survival with low RGC.

not controlled during the growing season. Seedlings were also potted and assessed for dormancy intensity[4] under greenhouse conditions at each outplant date.

The outplant site and the 1985 growing season combined to provide severe drought for our test. Mortality was high but this provided a unique opportunity to assess the predictive powers of RGP and dormancy intensity under severe outplant conditions.

Figures 3 through 5 illustrate the relationships between RGP, dormancy intensity

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[4] Dormancy Intensity = 10/number of days to budburst.

(DRI) and survival among a number of coastal Douglas-fir seedlots during 1985.

Within any of the three storage durations, RGP was a poor predictor of survival (Fig. 3). However, when considered as a group, seedlots with high RGP tended to survive better than those with low RGP. All seedlots had some roots greater than one centimeter in a one week-test (RGP = >1.0).

Survival was also reasonably well correlated with dormancy intensity (Fig. 4). Within a storage duration-planting date combination, those seedlings which burst bud rapidly consistently survived the best. This may be due to the fact that rapid initiation of growth (shoot and root) enhances a seedling's chances of occupying a larger rooting volume and capturing enough moisture and nutrients to survive through the rapid onset of drought.

To adequately determine the significance of this trend, we must expose a wider range of dormancy intensities to the same range of stresses. During the 1986 season, this hypothesis will be explored more fully under a range of moisture regimes.

Seedlings which burst bud rapidly tended to have low RGP (Fig. 5); however, as in the RGP versus survival relationship, no consistent trend existed among storage duration-planting date combinations.

CONCLUSIONS

- RGP assessment using the one week, 30°C/25°C (D/N) and Burdett's (1979) index method appears useful in identifying planting stock with a low probability of survival for a wide range of coastal species and stock types.

- An RGP value of 1.0 appears reasonable as a cutoff for silvicultural soundness to achieve a plantation survival target of 80 percent.

- RGP does not appear to have good predictive power beyond the roots/no roots determination.

- Evidence from Douglas-fir containerized stock suggests that stress resistance mechanisms related to cold hardiness and dormancy may play a significant role in seedling survival under stressful conditions.

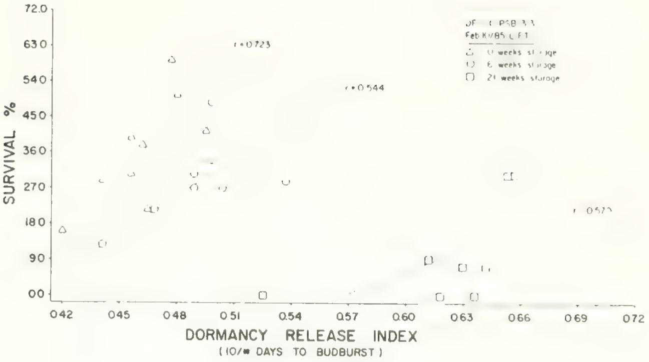

Figure 4 Under varying levels of outplant stress, Douglas fir seedlings which burst bud rapidly tend to survive better than those which burst bud slowly.

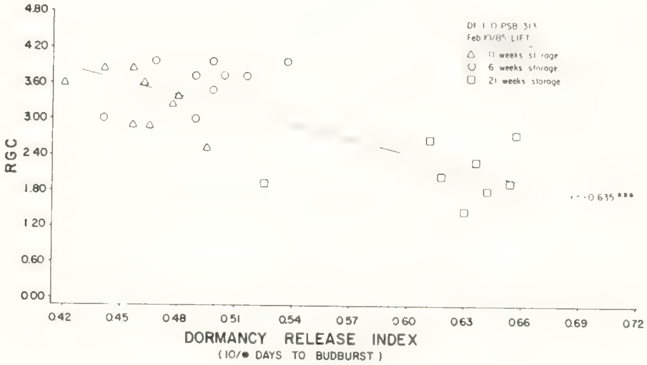

Figure 5 Containerized Douglas-fir seedlings which burst bud rapidly tend to have lower RGC.

- Challenge for the future is to use a more integrated approach to planting stock culture, allocation, and assessment by:

1. Developing a battery of stress resistance tests which accurately predict outplant survival and growth.

2. Using the battery of tests to provide an indication of stress prior to damage to facilitate preventative action and avoid batch culling.

3. Using test battery to improve nursery culture and seedling allocation through:

   - reducing the frequency of low quality seedlots
   - more adequately match seedling physiology to limiting site conditions.

Stem Canker Diseases of Douglas-fir in Nurseries[1]

Philip B. Hamm & Everett M. Hansen[2]

Abstract--Diseases that kill above ground portions of Douglas-fir formerly called "Top Blight," are listed. Disease recognition, time of infection, infection site, and causal agents are described.

"Top Blight" was a term coined in the early 1980's to describe death of aboveground portions of Douglas-fir in bare root nurseries in the Pacific Northwest. Because the damage was extensive, and the causal agents and times of infection were unknown, a research effort was undertaken with the support of the Industrial Forestry Association and Weyerhaueser Company. Five distinct diseases were identified as part of this complex. They are, in their order of occurence; Fusarium Hypocotyl rot, Upper stem canker, Lower stem canker, Phomopsis canker and Botrytus Canker (Hamm et al. 1985).

FUSARIUM HYPOCOTYL ROT

Mortality due to this disease appears in the 1+0 beds usually in July or August, generally associated with the first prolonged, hot weather of the summer (Fig. 1), and may continue through September or October. As the name implies, infection generally occurs in the hypocotyl region of the seedling but is not limited to that location. The causal agent, Fusarium oxysporum has also been seen attacking higher on the seedlings regardless of the point of infection, seedlings are quickly killed. Symptoms include stunting and chlorosis, leading to wilting and death. Dead and dying seedlings typically have a crooked top and tend to be randomly scattered throughout the nursery. Fusarium hypocotyl rot is the most damaging disease in Pacific Northwest nurseries at the present time.

Fusarium oxysporum in the past has been best known for causing root rot of 1+0 Douglas-fir (Bloomberg & Lock, 1972). Field symptoms are quite like Fusarium hypocotyl rot. Individual symptoms, however, are markedly different and are easily differentiated at the early stages. Roots of Fusarium hypocotyl infected seedlings are healthy in contrast to rotted roots associated with Fusarium root rot. Observations seem to indicate Fusarium root rot is more likely to occur in nurseries which do not regularly fumigate sowing areas.

UPPER STEM CANKER

This disease occurs in the fall (Fig. 1) of the 1+0 year. Upper stem canker has been responsible for spectacular epidemics in Northwest bare root nurseries. Phoma eupyrena and Fusarium roseum are the causal agents. Diseased seedlings are usually not noticed until their tops die, with affected seedlings often concentrated in discrete areas in nursery beds. Close observations of individual seedlings will identify small sunken areas on the stem, called cankers, that are often red in color. The margin between healthy and diseased tissue is distinct but once the stem is girdled and the top begins to dry, the upper lesion boundary is no longer easily identified.

Infection most often is associated with bark fissuring on the stem, apparently a normal physiological response to rapid growth. Fissures expose the xylem and heal quickly under normal conditions. Conidia (spores) produced by these fungi by chance land in these wounds and cause infections. Top killing is more severe when weather favoring fast seedling growth in the fall suddenly became cool and moist, slowing wound healing while favoring fungal spore production and dissemination. Spore production has often been seen on infected bark fissures. Infection can also occur through needles and lateral branchlets.

Damage may be more apparent than real. Depending on the height of cankers on seedlings,

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[1] Paper presented at the combined meeting of the Western Forest Nursery Council and Intermountain Nurseryman's Association, Olympia, WA, August 12-15, 1986.

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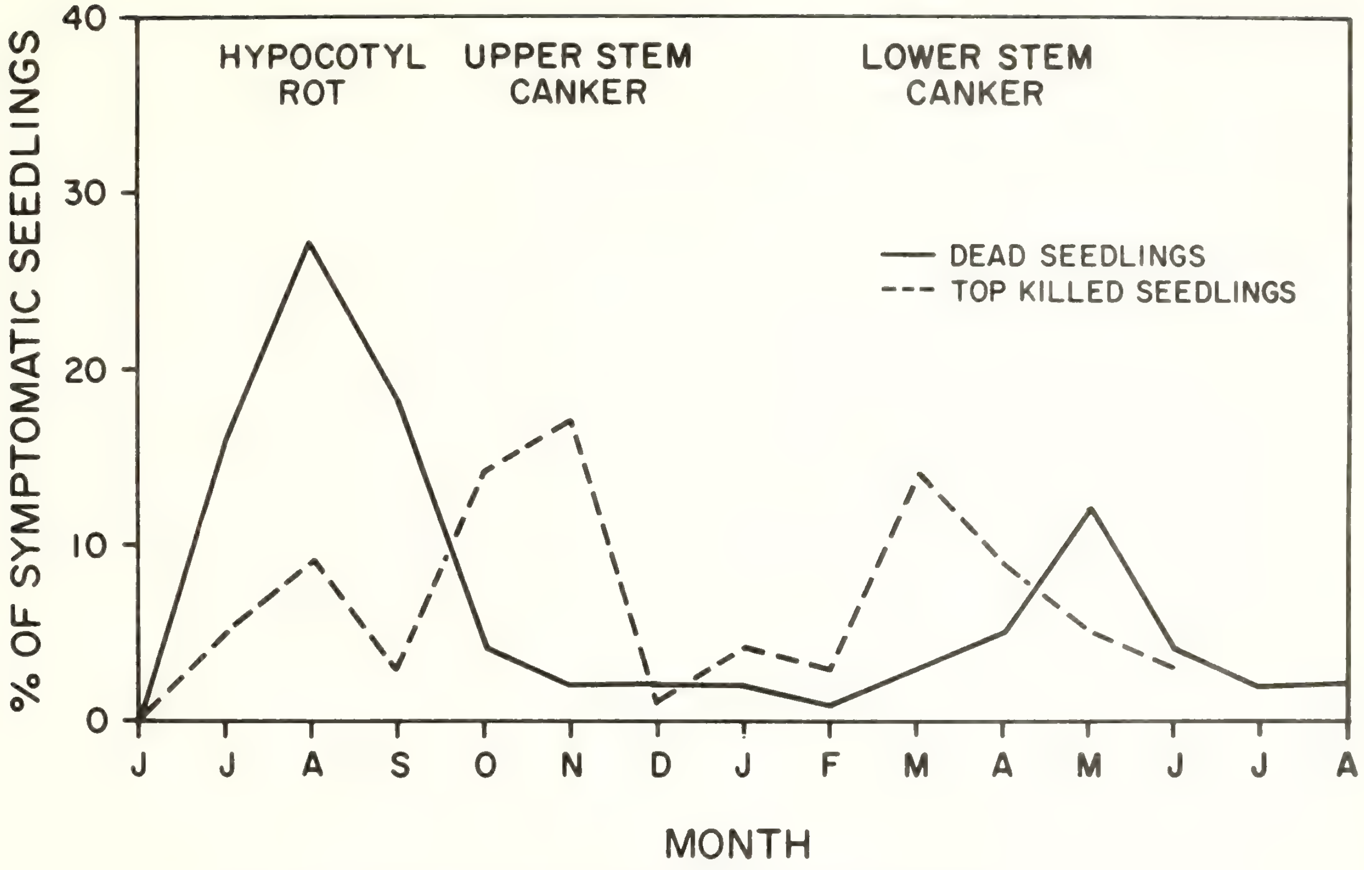

Figure 1. Chronology and symptom occurrence of three diseases affecting bare root Douglas-fir seedling in the Pacific Northwest.

the effect may be no more than early top pruning since cankers seldom expand downward. Loss is most likely to be due to seedlings failing to meet height packing standards.

LOWER STEM CANKER

The third disease identified was lower stem canker. This disease, also caused by Fusarium roseum and Phoma eupyrena, acting alone or together, attacks seedlings apparently sometime after dormancy in the fall and before growth begins in the 2+0 year (Fig. 1). Again a canker develops on the stem, but lower, usually at or near the soil line, and nearly always beneath the builtup collar of soil that forms around the lower stem. Because cankers are typically found below the lowest branches, seedlings are killed. Infections probably occur on the stem through abrasion wounds caused by the freezing and thawing of soil, blowing soil, or through needles, needle scars, or lateral buds smothered by the soil collar. Mortality is concentrated in lower areas and therefore may be confused with Phytophthora root rot. Roots of seedlings recently killed by lower stem canker, however, are always healthy.

Two other diseases reported to attack above ground portions of Douglas-fir in Pacific Northwest Nurseries could be confused with lower stem canker; Fusarium stem rot (Morgan 1983) and Phoma Blight (Kliejunas et al. 1985). Fusarium stem rot, caused by Fusarium roseum, is apparently identical to lower stem canker, but in our experience both Fusarium and Phoma are involved. Phoma blight caused severe needle loss at a nursery in California but seldom girdled seedlings in contrast to lower stem canker. Those reports identify problems specific to individual nurseries. From a regional view, both P. eupyrena and F. roseum are capable of causing mortality.

BOTRYTIS AND PHOMOPSIS CANKER

The last two disease situations occur during the 2-0 growing season and is caused by two agents, Botrytis cinerea and Phomopsis sp. Each causes a canker, almost always on the new growth but generally at different locations or times. Phomopsis is usually isolated from cankers forming at the base of new growth; usually within 4-6 weeks after shoot elongation. B. cinerea infects generally higher on the new

Table 1. Canker Diseases of Douglas-fir seedlings in the Pacific Northwest.

Disease	Fungi	Season	Location	Entry
Fusarium Hypocotyl Rot	Fusarium oxysporum	1+0 Summer	Hypocotyl and above	Soil abrasions direct
Upper Stem Canker	Phoma eupyrena Fusarium roseum	1+0 Fall	Mid-upper stem	Bark fissures Needle scars Lateral branches
Lower Stem Canker	Fusarium roseum Phoma eupyrena	1+0 Winter Spring	Lower stem	Soil Collars Soil abrasions Dead needles
Phomopsis Canker	Phomopsis sp.	2-0 Summer	Base of new growth	Bud scales
Botrytis Canker	Botrytis cinerea	2-0 Summer	New shoots	Wounds, lateral branches

growth, often entering the stem through a lateral twig. Both fungi cause stem girdling but do not kill seedlings. Trees generally recover and make packing standards. Botrytis canker was more frequently seen in high density beds but overall, much less damage was caused by both of these organisms then by any other "top blight" disease.

A summary of the canker diseases of Douglas-fir seedlings, fungi involved, time of infection, and location of infection on the seedling as well as mode of entry is listed in table 1.

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Kliejunas, J.T., J.R. Allison, A.H. McCain, and R.S. Smith. 1985. Phoma Blight of fir and Douglas-fir seedlings in a California nursery. Plant Disease 69:773-775.

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Occurrence of *Fusarium* on Conifer Tree Seed from Northern Rocky Mountain Nurseries[1]

R. L. James[2]

Fusarium spp. are common colonizers of conifer seed from northern Rocky Mountain nurseries. Assays of ponderosa pine, Douglas-fir, western larch, and spruce seeds indicate great variability in extent of contamination among seedlots. In some spruce seedlots almost 90 percent of the seeds tested were colonized by Fusarium; most seedlots of other species were much less contaminated. Fusaria are commonly found both on the seedcoat and within the endosperm of colonized seed. Seven species of Fusarium have thus far been isolated from seed, although F. oxysporum was encountered most frequently. Types of diseases associated with seedborne fusaria and techniques used to reduce levels of seed contamination are discussed.

INTRODUCTION

Investigations of diseases incited by Fusarium spp. indicate that these fungi are often introduced into both bareroot and container nurseries on conifer seed, sometimes causing extensive losses (Cooley 1983; Graham and Linderman 1983; James 1983b). Although Fusarium can infect conifer seed during flowering and cone formation (Anderson et al. 1980; Mason and Van Arsdel 1978; Sharma 1978), probably most infection occurs when cones or seed contact soil that harbors inoculum (James 1983a; Karrfalt 1983). Cones collected from squirrel caches often contain large populations of fungi including many pathogenic fusaria (James 1984b; James and Genz 1981; James and Genz 1982). During seed extraction, infection by Fusarium may intensify (Salisbury 1955), resulting in both seedcoat and endosperm colonization (James 1984a; James 1984b). Seedborne diseases often increase after prolonged seed and cone storage (Bloomberg 1969; Harman et al. 1978; Harvey and Carpenter 1975). Seed colonization by pathogens can also increase during the extended seed stratification periods that are common in conifer nurseries (Bloomberg and Trelawny 1970).

OCCURRENCE ON SEED

Investigations to elucidate the role of seedborne Fusarium spp. as incitants of disease in northern Rocky Mountain Nurseries began in 1981 (James and Genz 1981). Most evaluations have involved incubating seed from representative lots on a selective agar medium for Fusarium (Komada 1975). Placing seed directly on the medium gives an indication of abundance of Fusarium on the seedcoat. By aseptically dissecting seed and carefully separating the seedcoat from the endosperm, abundance of Fusarium on these two components can be determined.

Results of investigations to determine abundance of Fusarium on or within conifer seed are summarized in table 1. Many of these investigations have dealt with Douglas-fir (Pseudotsuga menziesii Dougl.)

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[1] Paper presented at the Western Forest Nursery Council Meeting, Tumwater, WA, August 12-15, 1986.

[2] R. L. James is Plant Pathologist, Cooperative Forestry and Pest Management, USDA Forest Service, Missoula, MT.

seed since disease incidence is usually most noticeable and widespread on this species, especially in container operations. Other species investigated include ponderosa pine (Pinus ponderosa Laws.), western larch (Larix occidentalis Nutt.), blue spruce (Picea pungens Engelm.) and Black Hills spruce (P. glauca var. albertiana (S. Brown) Sarg.). Results indicate that, in general, great variation exists in the occurrence of Fusarium among tested lots. Also, most lots tested have evidence for Fusarium within the endosperm as well as on the seedcoat, indicating either infection during seed formation or penetration of the seedcoat by the fungus.

As yet there have been no studies which have statistically evaluated the correlation between amount of seed infection and subsequent disease incidence. However such a correlation would be expected, since experience indicates that seedlots with poor germination and seedling emergence are generally infested by Fusarium to a greater extent than lots with better germination (James, unpublished).

TYPES OF DISEASES

Five types of diseases caused by seedborne fusaria are generally recognized on conifer seedlings. These include seed decay, pre-emergence damping-off or germination failure, post-emergence damping-off, top damping-off or cotyledon blight, and root disease or late damping-off (Bloomberg 1971; Matuo and Chiba 1966). Seed decay occurs when fungi penetrate the seedcoat, colonize it and break down internal seed contents (Bloomberg 1969). If decayed seed are sown, decreased germination will result and potentially pathogenic fungi introduced into seedbeds or containers (James 1985a; Landis 1976a). Pre-emergence damping-off occurs when the emerging radicle of germinating seed is attacked by fungi carried either on the seedcoat or present in soil (Bloomberg 1971; Graham and Linderman 1983). If the radicle is colonized by pathogenic fungi, decay results and no germinant emerges (Rathbun-Gravatt 1931). Post-emergence damping-off refers to disease of newly emerged germinants in which lesions often appear at the ground line, causing infected germinants to fall over (Bloomberg 1971; Landis 1976a). Decay of the germinant follows and sporulation of fungi may occur on decayed tissues. Top damping-off caused by Fusarium occurs as cotyledon blight (Mason and van Arsdel 1978), hypocotyl rot (Brownell and Schneider 1983), or stem rot (Morgan 1983). Cotyledon blight is especially common on species, such as ponderosa pine and Douglas-fir, which retain their seedcoats on the tips of cotyledons for extended periods after germination (Mason and van Arsdel 1978). Root disease caused by seedborne fusaria usually occurs on seedlings that are several months old. Disease results from decay of feeder roots (Pawuk and Barnett 1975); affected seedlings become slow growing and chlorotic (Landis 1976b) and may develop wilt symptoms and needle tip dieback (James 1983b; James 1984b; James 1984c). This disease may cause seedling mortality or reduced seedling vigor, which adversely affects outplanting survival (LaMadeleine 1979).

SPECIES OF FUSARIUM

Seven species of Fusarium have thus far been isolated from conifer seed at northern Rocky Mountain nurseries (table 1). The most common species isolated is F. oxysporum Schlect., an important pathogen of many different plants including conifer seedlings (Booth 1971; Cooley 1983; Gerlach and Nirenberg 1982). It is capable of causing vascular wilts (Booth 1971; Neergaard 1977) and cortical rots of seedling stems (Brownell and Schneider 1983; Morgan 1983) and roots (James 1983c; James 1984a). Although F. oxysporum exhibits a wide host range (Booth 1971; Gerlach and Nirenberg 1982), individual strains of the fungus, called formae specialis (f. sp.), usually infect only a few selective hosts (Gordon 1965; Snyder and Hansen 1940). Only one f. sp. (designated pini) has thus far been recognized for isolates that attack conifers (Gordon 1965). However, responses of different conifers to infection by several F. oxysporum isolates have sometimes been sufficiently variable to indicate that designation of additional f. sp. (other than pini) which attack conifers might be warranted (James and Gilligan 1984; Matuo and Chiba 1966). Additional pathogenicity tests on a wide range of conifer hosts will be needed to help clarify this issue.

Another Fusarium species commonly isolated from conifer seed is F. solani (Mart.) Sacc. (table 1). It is a commmon root decay organism that is especially damaging on agricultural crops (Booth 1971; Gerlach and Nirenberg 1982; Neergaard 1977). The fungus is occasionally associated with diseases of conifer seedlings (Landis 1976b; Merrill et al. 1981; Tint 1945). However, the pathogenic potential of seedborne sources of this fungus is unclear for conifer seedlings.

Table 1.—Abundance of Fusarium spp. on conifer seed from Northern Rocky Mountain Nurseries.

Species[1]	Nursery[2]	No. lots sampled	Percent lots w/Fusarium	Percent seed w/Fusarium		Associated Fusarium species[3]	Reference
				Seedcoat	Endosperm		
PP	CDA	1	100	4-12	4-20	FOXY	James 1986c
PP	MSN	1	100	2-4	—	FSAM; FACU; FSPO	James 1985b
PP	CTN	8	75	0-8	—	FOXY; FSOL	James & Genz 1982
PP	CTN	2	100	—	—	FOXY	James & Genz 1981
DF	CDA	5	100	1-22	2-8	FOXY; FAVE	James (unpub. 1986)
DF	UIN	3	100	6-43	—	—	James & Dumroese (unpub. 1986)
DF	CDA	5	80	0-10	—	FOXY; FSOL	James 1983d
DF	PCN	4	75	0-7	—	FOXY; FACU	James 1986a
DF	CTN	4	75	0-13	—	FOXY; FSOL	James 1984a
DF	MSN	1	100	4	4	FOXY; FSOL	James 1983b
WL	NN	2	100	5-88	—	FOXY; FSAM	James 1986b
BS	TN	5	100	0-52	—	FOXY; FSOL; FTRI	James 1985c
BHS	TN	3	100	18-78	—	FOXY; FSOL; FTRI	James 1985c

[1] PP = ponderosa pine; DF = Douglas-fir; WL = western larch; BS = blue spruce; BHS = Black Hills spruce

[2] CDA = USDA Forest Service Nursery, Couer d'Alene, ID; MSN = Montana State Nursery, Missoula, MT; CTN = Champion Timberlands Nursery, Plains, MT; UIN = University of Idaho Nursery; Moscow, ID; PCN = Plum Creek Nursery, Pablo, MT; NN = Nishak Nursery, Bonners Ferry ID; TN = North Dakota Forest Service Nursery, Towner, ND.

[3] FOXY = F. oxysporum; FSAM = F. sambucinum; FACU = F. acuminatum; FSPO = F. sporotrichiodes; FSOL = F. solani; FAVE = F. avenaceum; FTRI = F. tricinctum.

Other species of Fusarium isolated from conifer seed include F. acuminatum Ell. & Ev., F. avenaceum (Fr.) Sacc., F. sambucinum Fuckel, F. sporotrichioides Sherb., and F. tricinctum (Corda) Sacc. (table 1). Although some of these fungi are pathogenic (James 1985c; James and Gilligan 1984), many are probably saprophytic (Booth 1971; Gerlach and Nirenberg 1982). Many seedborne isolates of these fungi need to be evaluated for their pathogenic potential.

DISEASE CONTROL

The extent of Fusarium contamination on seed varies great among different conifer species and seedlots (table 1). These differences may be related to cone collection, storage, and seed extraction practices. For example, cones collected from squirrel caches often have high levels of fungal contamination. Also, cones and seed stored under damp conditions for longer time periods are more prone to damage by fungi.

Seed treatment before sowing may reduce disease losses caused by seedborne fusaria (Johnson and Harvey 1975; Johnson and Linton 1942). Most growers soak seed in water to condition them for sowing; some use standing water and others a running water rinse (James 1984a). If infected seed is soaked in standing water, fungal propagules can spread, causing widespread infection (James 1983b). However, placing seed under a running water rinse can reduce seedcoat contamination and does not spread infection (James 1983b; James 1984a).

Sterilants such as hydrogen peroxide and sodium hypochlorite (commercial bleach) have frequently been used to reduce fungal contamination and enhance germination of conifer seed (James and Genz 1981; Partridge et al. 1985). Hydrogen peroxide usually reduces or eliminates fungal contaminants (Barnett 1976; James and Genz 1981). The effect of hydrogen peroxide on seed germination has been variable. For example, some investigators (Edwards and Sutherland 1979; James 1983b) report reduced seed germination, whereas others (Ching and Parker 1958; James and Genz 1981; Mason and van Arsdel 1978) report improved germination. Detrimental effects of hydrogen peroxide generally increase with chemical concentration and exposure period. Sodium hypochlorite usually reduces fungal contamination (James and Genz 1981) and sometimes enhances seed germination (Partridge et al. 1985).

Several fungicides have been used for seed treatments to reduce damping-off caused by seedborne pathogens (Mittal and Sharma 1981; Strong 1952). However, reports of fungicide toxicity to seed and germinants have limited their use (Cooley 1983; James 1983b; Lock et al. 1975). For example, use of captan has resulted in reduced seed germination (Peterson 1970), and has caused seedling injury following germination (Cayford and Waldron 1967; Lock et al. 1975). Thiram, another common seed-treatment fungicide, has reduced seed germination (Dick et al. 1958; Shea 1959) and caused deformed germinants (Hedderwick and Gadgil 1966). Effectiveness of seed-treatment fungicides is apparently related to dosage levels (Hamilton and Jackson 1951), activity spectrum against target organisms, development of resistant fungal strains, and persistence on seed (Sutherland and van Eerden 1980).

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Management of the Top Blight Disease Complex[1]

Alan Kanaskie[2]

Abstract.--The "top blight disease complex" refers to five separate but related diseases affecting above-ground portions of bareroot Douglas-fir seedlings. Disease losses can be reduced by altering cultural practices or applying fungicides[3]. The following paper provides practical approaches and techniques for reducing losses from top blight.

INTRODUCTION

The top blight disease complex refers to diseases of above-ground portions of bareroot Douglas-fir seedlings. They are described elsewhere in these proceedings by P. Hamm. Five distinct diseases comprise the complex (Hansen and Hamm 1985):

1. Fusarium hypocotyl rot. Caused by *Fusarium oxysporum*. Affects hypocotyl region and above during summer of the 1-0 year;

2. Upper stem canker. Caused by *Phoma eupyrena* and *Fusarium roseum*. Affects mid to upper stem in late summer and early fall of the 1-0 year;

3. Lower stem canker. Caused by *Fusarium roseum* and *Phoma eupyrena*. Affects lower stem near soil level from winter through flush of new growth on 2-0 seedlings;

4. Phomopsis canker. Caused by *Phomopsis* sp.. Affects new growth of seedlings during summer of the 2-0 year;

5. Botrytis canker. Caused by *Botrytis cinerea*. Affects new shoots during summer of the 2-0 year.

Losses to top blight can be substantial. Mortality exceeding 30% of the crop has been caused by both hypocotyl rot and lower stem canker.

Disease occurrence varies widely among nurseries. Some nurseries may experience recurrent epidemics of one disease only, while others may suffer from all five. Disease severity also varies highly from year to year, and appears practically unpredictable. In a given nursery, a top blight disease may be epidemic one year and absent the next.

Factors influencing occurrence and severity of top blight are poorly understood. Consequently, disease prediction is difficult. Fortunately, research by Oregon State University, the USDA Forest Service, and Weyerhaeuser Company, has greatly improved our understanding of these diseases and of techniques for controlling them. The purpose of this paper is to present management strategies, based on current knowledge, that should reduce losses to diseases of the top blight complex.

APPROACH TO DISEASE MANAGEMENT

Occurrence and severity of top blight diseases apparently are governed by a complex of factors including weather, sowing date, pathogen populations, soil moisture, etc. - in short, anything that affects the seedling or the pathogens likely affects disease. In plant pathology jargon this concept is called the "disease triangle", which states that disease results from the interaction of the plant (host) and pathogen as regulated by the environment. This is the basis for understanding disease development and should also form the basis for control strategies.

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[3] The use of company names or proprietary products in this paper does not constitute endorsement or guarantee by the Oregon Forestry Department, and does not imply criticism of those not mentioned.

Nursery cultural practices alter the environment, the seedling, and even the pathogen. However, no single practice stands out as the trigger to an epidemic. Fumigation and fungicides can reduce disease in many cases, but even the most intense chemical regime does not guarantee a disease-free crop. In fact, some of the most severe top blight losses have occurred in nurseries despite fumigation and fungicide treatments.

The suggested approach to disease management is to consider the probable effects of nursery practices on disease development and, whenever possible, adjust them in a way that should reduce disease severity. Even though a single cultural practice may have little apparent effect on disease incidence, the cumulative effect of adjusting several different practices should reduce losses.

The remainder of the paper presents several opportunities for reducing disease losses. Many recommendations, particularly fungicide treatments, are based on several years of data from Oregon, Washington, and California. Other suggestions, concerning soil splash and soil moisture conditions, rely on observations over several growing seasons. Finally, some recommendations are unproven logical deductions. Suggestions may change as understanding of disease dynamics improves.

THE FIRST STEP - RECOGNIZING THE PROBLEM

The most important step in disease management is recognizing and identifying the problem in your nursery. Few nurseries will have all diseases, and the same disease may behave differently in one nursery than in another. To assume that all diseases are present could result in wasting resources to control insignificant diseases. Accurate identification allows a focused and efficient control effort.

Pathologists, and many nursery personnel, are adept at disease identification, but identification is only part of the issue. Understanding disease development over time in _your_ nursery is critical. This can be accomplished by assigning _disease responsibility_ to someone (a consultant or nursery employe are logical choices) who provides nursery-specific monitoring and understanding of diseases over time. This person also could maintain liaison with pathologists from universities and government agencies.

DISEASE MANAGEMENT BEFORE SOWING

Cover Crops

Cover crops are used commonly in forest nurseries to protect soil, replenish nutrients, and maintain organic matter content. They may increase or decrease disease occurrence, or they may have no effect.

In the pacific northwest, preliminary data indicate that cover crops of beans, peas, oats, and sudan grass result in higher populations of soil-borne _Fusarium_ than in bare fallow areas[4]. Bare fallow with frequent tillage has reduced pathogen and nematode levels in British Columbia forest nurseries[5]. However, the correlation between soil pathogen populations and disease incidence has not been established.

High soil pathogen populations likely increase probability of disease occurrence, particularly for hypocotyl rot. Nurseries that experience chronic losses from hypocotyl rot could reduce _Fusarium_ levels by bare fallowing rather than cover cropping.

Monitoring Populations of Soil-Borne Pathogens

The most important pathogens of the top blight complex, _Fusarium_ and _Phoma_, occur in the soil. _Fusarium_ populations can be quantified by assaying soil samples on culture media that allow only _Fusarium_ and a few other fungi to grow. Abundant _Fusarium_ in the soil appears to increase probability of Fusarium-caused disease[6]. Techniques for selective isolation of Phoma from soil are unavailable, and the importance of Phoma populations are unknown.

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[4] Hamm, Phil. 1986. Personal conversation. Oregon State University, Corvallis, Oregon.

[5] Sutherland, Jack. 1984. Personal conversation. Pacific Forest Research Centre, Victoria, British Columbia.

Reliable correlations between soil pathogen counts and amount of disease have been difficult to establish. It is thought that soil populations could form the basis for disease prediction. Consideration of soil pathogen counts with disease history, crop history, and other factors has enabled crude disease prediction in several nurseries. British Columbia, Washington Department of Natural Resources, and private consultants successfully use soil counts as input to pest management decisions (McElroy 1984).

How much Fausarium is too much? Should I fumigate if I have 1,500 propagules of Fusarium per gram of soil? It is doubtful that anyone can give an answer that will apply to all nurseries. However, after monitoring soil pathogen counts and disease levels for a few seasons, a nursery should be able to address these questions with some confidence. It is certainly an improvement over complete guesswork. Soil pathogen assays are available from certain consulting firms. Some nurseries chose to do their own assays.

Fumigating Nursery Soils

Fumigation can effectively reduce soil pathogen populations and improve conifer seedling yield and quality (Bloomberg 1965, Sinclair et al 1975). Methyl Bromide/chloropicrin is most widely used and is highly effective. Efficacy of other chemicals is discussed elsewhere in these proceedings by F. McElroy and by Y. Tanaka.

Despite demonstrated effectiveness for disease conrol at many nurseries, fumigation does not guarantee a disease-free crop. Conversely, nurseries have produced excellent crops without fumigation. Pathogens can recolonize fumigated soils during the time between fumigation and sowing, and although they may not attain levels as high as those before fumigation, they may be high enough to initiate serious disease. It has also been speculated that fumigation alters the balance of microflora in a way that gives advantage to pathogens growing among reduced populations of antagonistic organisms.

Fumigation is an expensive treatment, so the question often becomes "is it worth it?" Reliable disease prediction would help answer that question. Other benefits such as weed control, as well as pesticide use regulations and economics must be weighed along with disease control benefits. Soil assays and continual evaluation of fumigation effectiveness can be used to decide whether or not fumigation is necessary.

Seed Treatments

The occurrence of Fusarium-caused disease in 1-0 beds that have been fumigated prompts questions about the source of Fusarium. Fusarium spores can blow into a field on dust or debris particles or they can recolonize upward from soil beneath the level of fumigation (Marois et al 1983). Fusarium occurs in and on Douglas-fir seed (Bloomberg 1966), and seed-borne Fusarium can cause seedling disease (Graham and Linderman 1983, James 1985). However, the importance of Fusarium on seed in bareroot nurseries is poorly understood.

It seems reasonable to assume that Fusarium on seed could contribute to increased disease. Many seedlots will have little or no Fusarium. Those that do can be detected by assaying seed samples on culture media selective for Fusarium (the same media is used for the soil assays mentioned earlier). Monitoring disease levels in seedlots with different pathogen levels will add another bit of information to nursery-specific understanding of disease behavior.

Treating seeds with fungicides has had variable success, and often has reduced seed viability (Sutherland 1984). Rinsing seed for up to 48 hours in running water should remove much of the surface Fusarium[7]. Strong recommendations about seed treatment will be possible only after additional research and nursery field studies.

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[6] McElroy, Fred. 1985. Personal conversation. Peninsu-Lab, Inc., Kingston, Washington.

[7] James, Robert. 1986. Personal conversation. USDA Forest Service, Missoula, Montana.

MANAGING SPECIFIC TOP-BLIGHT DISEASES

Fusarium Hypocotyl Rot

Seed treatment.

Fusarium on seed can cause hypocotyl rot in Douglas-fir seedlings[8]. The effectiveness of treating seeds with fungicides needs clarification through research. If *Fusarium* seedlot assays reveal abundant *Fusarium*, rinsing seeds in running tapwater for 48 hours should reduce probability of hypocotyl rot.

Sow seed early.

Observations strongly suggest that sowing as early as possible reduces amount of hypocotyl rot. Early sowing has also been recommended to reduce hypocotyl rot severity in sugar pine seedlings (Brownell and Schneider 1985). Early sowing may allow seedlings to attain large size and develop resistance to hypocotyl rot before the environment of the nursery bed favors disease development.

Fertilization.

Sinclair et al (1975) reported that fertilization with urea increased severity of *Fusarium* root rot of bareroot Douglas-fir seedlings. Summer mortality, which may have been partly due to hypocotyl rot, was highest in seedlings receiving pre-sow urea. A "best guess" recommendation at this time is to avoid urea fertilization during the first 8 weeks following sowing. Effects of form of nitrogen fertilization and timing of its application are being studied in several northwest nurseries during 1986[9].

Irrigation.

Irrigation regimes, particularly those used for cooling during summer, appear to affect hypocotyl rot severity. Elsewhere in these proceedings, Ken Russell discusses a strategy of deep watering (as opposed to frequent shallow watering) to reduce hypocotyl rot losses.

During 1986 at the Oregon State Forest Nursery, uneven irrigation affected hypocotyl rot occurrence. Portions of beds within 10 feet of sprinkler heads remained wet longer than areas between 10 and 15 feet of sprinkler heads, indicating that more water was deposited at the heads than between them. In parts of the nursery where hypocotyl rot occurred, disease severity in the dry areas was nearly double that occurring in wet areas (35% versus 20%, respectively). Drier soils may have permitted higher temperatures near ground level which stressed seedlings and favored disease development (Brownell and Schneider 1985).

Fungicides.

Among fungicides tested in Pacific Northwest nurseries from 1983-1985, Benlate, Daconil 2787 and Chipco 26019 (Chipco not registered for forestry use) appeared most effective, but effectiveness was highly variable (Cooley and Kanaskie 1986). Other factors such as weather and cultural practices appear capable of overriding the effects of fungicides applied as often as twice per week[10]. If fungicide treatments are used, begin treatments at full emergence and follow label rates. Tank mixes and alternating chemicals are recommended.

Preliminary studies suggest that Bayleton may reduce incidence of hypocotyl rot[10]. Further testing of this material is recommended.

Upper Stem Canker

Cultural practices.

Upper stem canker appears most severe in seedlings whose growth is prolonged through late summer into early fall, and in seedlings grown at very high densities (50-75 trees per square foot). Infections often are associated with splits in the stem which may result from rapid seedling diameter growth in late summer. Disease risk should decrease if cultural practices such as fertilization and irrigation are used to limit rapid diameter growth and to prevent succulence from continuing into fall. If upper stem canker is a serious concern in your nursery, consider inducing bud-set earlier than normal.

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[8] Littke, Willis. 1986. Personal conversation. Weyerhaeuser Company Centralia Forestry Research Center, Centralia, Washington.

[9] Cooley, S. J. and A. Kanaskie. 1986. Unpublished study plan - effect of nitrogen fertilization on disease of Douglas-fir seedlings in the first growing season. USDA Forest Service, Portland, Oregon.

[10] Kanaskie, A. 1986. Unpublished data on file at Oregon State Department of Forestry, Salem, Oregon.

Fungicides.

Chipco 26019, Daconil 2787, Difolatan, and Benlate were most effective in Pacific Northwest nurseries, but only Daconil 2787 and Benlate are registered (Cooley and Kanaskie 1986). Treatment should continue through budset of the 1-0 year. Tank mixing and alternating chemicals are recommended. Coverage of the seedling stem (not foliage) is important; spreader-stickers should enhance performance. Time applications so irrigation or rain will not wash materials off before they dry.

Lower Stem Canker

Avoid creating areas of poor drainage.

During evaluations of fungicides, lower stem canker occurrence appeared more strongly related to wet areas in the beds than to fungicide treatments (Cooley and Kanaskie 1986). Increased disease has also been observed in beds receiving heavy tractor traffic during winter months[11]. Ripping tractor paths, eliminating low spots during land-planning, and limiting tractor traffic on wet fields should help reduce occurrence of lower stem canker.

Soil splash on seedling stems.

The accumulation of rain- or irrigation-splashed soil on lower foliage and stems of seedlings, called "soil cones" or "soil collars", is strongly associated with lower stem canker (Hansen and Hamm 1985, Kliejunas et al 1985, Morgan 1983). Soil accumulation usually begins during summer of the 1-0 year and continues through winter. Soil collars put the soil-borne pathogen in close contact with seedlings and may provide an environment conducive to disease development.

Prevention of soil collar formation can reduce losses to lower stem canker. The addition of redwood mulch or shade lath reduced soil cone formation and Phoma blight incidence on fir and Douglas-fir in a northern California nursery (Kleijunas et al 1985). At a Washington nursery during 1983, fewer seedlings had lower stem cankers in moss-covered beds (no soil collars) than in moss-free beds (abundant soil collars)[12].

Establishing a thick carpet of moss appears to be the simplest and most economical method of preventing soil collars, but this approach will only work in nurseries with naturally-abundant moss. Mosses are often eliminated from nursery beds with herbicide treatments. However, choosing herbicides that do not kill mosses will allow moss to develop during the 1-0 year.

Of the shade lath and mulch treatments, the latter is most practical. Other types of mulch may be effective and should be field-tested. A liquid latex acrylic sealant was tested in northern California, but it was ineffective[13]. Mulch treatments must be applied before soil buildup occurs.

Fungicides.

Field trials indicate generally poor control with fungicides. Fungicide ineffectiveness for preventing lower stem canker probably occurs because: 1) fungicides may not penetrate soil collars, and; 2) weather can prevent timely applications during the likely period of infection (winter). Of materials tested, Daconil 2787 was most effective; Benlate and Difolatan (Difolatan not registered) had variable effectiveness (Cooley and Kanaskie 1986). Exact time of infection is unknown, so fungicides may need to be applied from budset through shoot emergence in spring.

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[11] Littke, Willis. 1986. Personal conversation. Weyerhaeuser Company Forestry Research Center, Centralia, Washington.

[12] Kanaskie, Alan. 1984. Unpublished data. Weyerhaeuser Company Centralia Forestry Research Center, Centralia, Washington.

[13] Kliejunas, John. 1985. Efficacy of Soiul Seal concentrate for reducing soil cone formation in nursery beds at Humboldt nursery, unpublished report. USDA Forest Service, SanFrancisco, California.

Botrytis Canker

Cultural practices.

Reducing seeding density improves air flow and lowers humidity, providing conditions unfavorable for disease development. Avoid seedling injury: anything that injures seedlings - machinery, frost, excessive fertilization, herbicides - increases the risk of Botrytis-caused losses. Clipped seedling tops following top-mowing may also encourage Botrytis buildup.

Fungicides.

Benlate, Daconil 2787, and vinclozolin (Ronilan, Ornalin) are among chemicals registered for Botrytis in bareroot conifer nurseries. Daconil appeared most effective in northwest nurseries, and Benlate yielded variable results (Cooley and Kanaskie 1986).

Fungicide applications, if necessary, should begin when disease appears. Apply with techniques that put the chemical on the target, i.e., use rollers to bend seedlings during spraying, or use high tank pressures or atomizing nozzles. Reduce likelihood of developing fungicide resistance by applying minimum effective rates and alternating (not tank mixing) chemicals with different modes of action. In many cases, fungicide treatments for other top blight diseases may provide adequate Botrytis control.

Phomopsis Canker

Phomopsis canker usually is not severe enough to warrant specific fungicide treatments. Information on fungicide effectiveness is limited, but protective treatments during the flush of growth should be effective, and should be tested.

COMMENTS ON FUNGICIDE USE

Fungicide treatments can be cost-effective in bareroot nurseries, particularly for diseases that cause mortality. Because fungicide application costs tend to be small, even slight increases in disease-free seedlings may pay for treatment costs (Cooley and Kanaskie 1986). However, applying fungicides only when necessary will improve economic returns and may prevent development of fungicide-resistant pathogens.

Most fungicide testing has yielded variable results within and among nurseries. Fungicide evaluations should be ongoing and nursery specific - it may take several years to determine the most effective materials. Effectiveness can only be evaluated if treated areas are compared to untreated areas; leaving a few small areas untreated whenever applying fungicides will provide a wealth of information.

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Phytophthora Root Rot in Forest Nurseries of the Pacific Northwest[1]

Philip B. Hamm and Everett M. Hansen[2]

Abstract--Phytophthora root rot continues to cause significant damage in some Pacific Northwest nurseries. Recognition of the disease is discussed as is fungal biology, host-pathogen interactions and origin in nurseries.

Phytophthora root rot in Pacific Northwest bare root nurseries was first reported in 1975, causing severe damage to Douglas-fir (*Pseudotsuga menziesii*) (Pratt et al. 1976). That report and subsequent ones (Hamm & Hansen 1981, 1982A, 1982B, 1983) have identified the *Phytophthora* species that cause damage in Northwest nurseries (Table 1) and the susceptibility of conifer seedlings grown in the region (Table 2). *Phytophthora* root rot has rarely been found in containerized situations, due to the ability to regulate contamination from water, media and pots.

Table 1. Species of *Phytophthora* that cause root rot in Pacific Northwest Nurseries.

P. drechsleri
P. pseudotsugae
P. cinnamomi
P. cactorum
P. cryptogea
P. megasperma Douglas-fir
P. megasperma Broad host range

Typically, symptoms of *Phytophthora* infection are not exhibited until seedlings are approaching their second growing season, or following transplanting. Pre and post-emergence damping off can occur during the first year, but this is more commonly due to *Fusarium* and *Pythium* species. By early spring of their second year, root rotted trees begin to yellow as they break dormancy. Damage is often concentrated in low areas in the field where surface water accumulated during winter. By early summer the most severely infected seedlings have died. Seedlings not as severely infected commonly exhibit delayed bud break, poor elongation of the new terminal and lateral shoots (giving a bottle brush appearance) and chlorosis. Seedlings with light infection may not express distinct top symptoms. Below ground, severe *Phytophthora* damage is easily recognized. In trees moderately to severely rotted, root systems noticeably lack lateral roots and have a shortened tap root; less severely rotted trees possess fewer lateral roots and a shortened tap as compared to healthy seedlings. Light scraping of the root cortex of diseased seedlings with a knife exposes the cambial region and reveals the characteristic reddish brown discoloration of *Phytophthora* infected tissue in contrast to white, healthy tissue further up the stem.

Table 2. Conifer seedlings susceptible to *Phytophthora* root rot. Susceptibility of species marked with an asterisk (*) is known only from artificial inoculations.

	Douglas fir		Western white pine
	Western Hemlock		Grand fir
*	Mt. Hemlock		White fir
*	Incense cedar		Noble fir
*	Sitka Spruce		Shasta red fir
*	Englemann Spruce		Pacific Silver fir
*	Lodgepole pine	*	Western larch
	Sugar pine		Ponderosa pine

With the exception of *P. cinnamomi*, these species of *Phytophthora* are quite adapted to the environmental conditions found in Pacific Northwest nurseries. Roth and Kulman (1966) concluded that *P. cinnamomi* was not a threat to the Douglas-fir forests of the region due to its requirement for simultaneous warm soil temperatures and high soil moisture. This requirement apparently holds for nurseries as well since *P. cinnamomi* has caused substantial

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[1] Paper presented at the combined meeting of the Western Forest Nursery Council and Intermountain Nurseryman's Association, Olympia, Washington, August 12-15, 1986.

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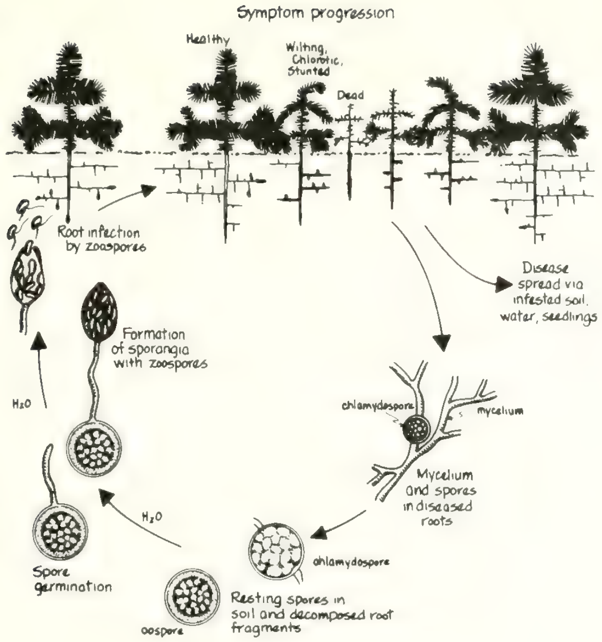
Symptom progression
Healthy
Wilting, Chlorotic, Stunted
Dead
Root infection by zoospores
Disease spread via infested soil, water, seedlings
Formation of sporangia with zoospores
H₂O
chlamydospore
mycelium
Mycelium and spores in diseased roots
H₂O
chlamydospore
Spore germination
Resting spores in soil and decomposed root fragments
oospore

Figure 1. -- Life cycle of Phytophthora spp. on conifer seedlings.

damage only in: 1) a warmer coastal nursery; 2) in a bare root seed orchard; and 3) in containerized seedlings propagated for transplanting to a seed orchard. In contrast, the remaining *Phytophthora* species have been found in most major bare root nurseries in Oregon, Washington and into British Columbia. These species apparently survive well in nurseries under normal conditions. Moist periods favor production of sporangia, which in turn develop and release swimming spores called zoospores (Fig. 1).

While dissemination of zoospores in the soil is quite limited (Duniway 1976), widespread infection can result if surface water accumulates or water or equipment moves through contaminated blocks. Zoospores are attracted to exudates from roots of susceptible hosts. This may partially explain why root pruned transplants are sometimes severely damaged. Zoospore production and dissemination decrease with declining soil moisture, although root rot severity on infected trees may continue to increase through the summer. Irrigation extends the period of dissemination on poorly drained soils.

Phytophthora can be isolated from live, infected seedlings throughout the year. Long-term survival apparently is by resistant structures (e.g., oogonia, chlamydospores) in soil or in infected roots or dead trees (Hansen et al. 1980). Fortunately other factors must be limiting disease development on forest sites. These *Phytophthora* species lower survival of infected outplanted seedlings but do not spread from infected stock to adjacent healthy trees (Hansen et al. 1980).

Losses due to *Phytophthora* root rot are highly variable. Factors such as crop type (1+0, 2+0, 2+1 etc.) seedling species, moisture (artificial and natural) and/or soil type are important. Most extensive damage in past years has been seen in transplanted Douglas-fir. As mentioned previously, wound sites on transplanted seedlings apparently attract zoospores but high soil moisture due to watering after transplanting (favoring zoospore formation), seedling stress from uplifting, storage, root pruning, etc., and transplanting into unfumigated, possibly heavy and warming spring soils and the amount of *Phytophthora* present on seedlings or in the soil, probably all contribute to disease severity. Substantial losses also occur in 1+0 and 2+0, usually when seedlings have been planted in areas where water is allowed to stand particularly in bed ends or low spots in the field (Hansen et al. 1979).

Susceptibility of the tree species grown in Northwest nurseries varies as does the aggressiveness of the *Phytophthora* species. *P. cinnamomi*, where conditions allow, and *P. cryptogea* have been shown to be highly aggressive to most native conifers (8); *P. megasperma* Douglas-fir (Hamm and Hansen 1981, Hansen and Hamm 1983) is generally less aggressive but more damaging than *P. drechslei* and *P. cactorum*, while *P. megasperma* Broad host range (Hamm and Hansen 1981, Hansen and Hamm 1983) and *P. pseudotsugae* are usually only weakly aggressive. Interestingly, these later two species are the most often isolated from diseased seedlings. Pathogenicity information is based on controlled *in vitro* testing for a period of 8-10 weeks. The extended length of time seedlings are grown in nurseries (1-3 years), coupled with a long favorable environment, can allow even the least aggressive of these fungal species to cause significant damage in a nursery setting. Generally, hemlock, true firs and Douglas-fir seedlings are the most susceptible to *Phytophthora* infection, followed by spruce and pine. Western red cedar was undamaged by any *Phytophthora* species in our tests (Hamm and Hansen 1982B, S.A. Cooley & P.B. Hamm unpublished).

Host specificity was generally not evident, except that isolates of *P. cryptogea* from sugar pine caused significantly greater root rot on that host than did isolates of the same species from other hosts (Hamm and Hansen 1982B). Although both groups of *P. megasperma* are pathogenic on most conifers tested, *P. megasperma* Douglas-fir is pathogenic only to conifers while *P. megasperma* Broad host range has a larger host range (Hansen and Hamm 1983).

The origin of Phytophthora in nurseries of the region is an ongoing question. Most likely Phytophthora was present in the soil prior to nursery establishment. The species found (except P. pseudotsugae) are common agricultural pathogens and since most nurseries were established on long used agricultural sites, their prior presence seem reasonable. This is supported by the fact that some isolates which attack Douglas-fir can cause disease on soybean and alfalfa. The occurrence of many of the same Phytophthora species in many nurseries is best explained by movement of transplant stock between nurseries.

During the twelve years since Phytophthora was first reported in the Pacific Northwest bare root nurseries, these fungi have been directly responsible for the closure of two large nurseries and substantial reduction in production in several others. Dollar loss also occurs through poor survival of infected seedlings outplanted to forest sites (Hansen et al. 1980). More basic and applied research is needed to better understand the biology of these organisms and to develop integrated control strategies. This point is examplified by the continual, sometimes extensive losses that occur due to Phytophthora throughout the region.

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Management of Phytophthora Root Rot in Pacific Northwest Conifer Nurseries[1]

Sally J. Cooley[2]

Abstract.--Various cultural and chemical strategies to reduce the incidence and severity of Phytophthora root rot on conifers in bareroot nurseries are discussed.

Management of Phytophthora root rot can be approached culturally and chemically. Both methods give some control of the disease. The best strategy is to use good cultural practices and supplement, when needed, with fungicides and fumigants.

CULTURAL MANAGEMENT

Cultural practices, which discourage the development of Phytophthora root rot, include good water management, sanitation, and use of tolerant or resistant species in areas where Phytophthora root rot is or may be a problem.

Water Management

Because the development and spread of Phytophthora is very dependent on high soil moisture and water movement, management of water in the nursery is integral to controlling the disease. A number of things are often involved when good water management is practiced.

1. Ideally, your nursery should be located on light, well-drained soil; realistically, very few nurseries in the PNW have the good fortune to be situated on light-textured soils.

2. Those nurseries with heavy, slow-percolating soils must add drainage systems. Subsurface drainage systems are common in PNW nurseries; some have been installed at the very onset when the area was initially developed and some have been installed years later after the field has grown numerous crops.

3. Drainage of surface water from nursery beds and onto roads or ditches can be enhanced by crowning fields and ensuring that all bed areas slope downwards towards roads or ditches.

4. Beds can be raised above the level of the tractor paths to allow water to run from beds into paths. When paths become compacted or beds are not raised, tractor paths can be sub-soiled to allow water to drain into the cut made by the sub-soiler. Several PNW nurseries routinely sub-soil 1-year-old fields in the fall before the onset of rainy weather. Similarly, wrenching will enhance drainage in the bed itself.

5. Low, poorly drained areas in fields should be noted and, after the crop is lifted, these areas can be filled in or taken out of production until corrective work can be done on them.

6. Irrigation practices often influence the development of Phytophthora root rot. Watering needs should be coordinated to avoid constant saturation of soils, particularly during the spring, summer, and fall when the fungus is active. Irrigation for cooling, pesticide application, or following fertilization should coincide as much as possible with routine irrigation. Over-irrigation and alternating drying and saturation should be avoided, particularly in areas known to be infested with the fungus.

Sanitation

Sanitation practices are a vital part of management of any disease. Phytophthora root rot is no different. Diseased seedlings should be removed from nursery beds and disposed of, particularly if you do not plan to fumigate prior to the next crop. Rogued seedlings and packing house culls should not be returned to the fields as organic matter. Resting spores are able to survive in dead plant tissue and could serve as a source of infection if left in the field. Even composted culls are suspect. We feel that composting will not kill 100% of Phytophthora inoculum in seedling tissue; various fungi, including Pythium (a close relation to Phytophthora), have been recovered from seedlings composted for over 1 year.

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[1] Paper presented at the Western Forest Nursery Council Meeting, Tumwater, Washington, August 12-15, 1986.

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Diseased seedlings and seedlings from diseased areas of a nursery should not be moved to other nurseries or to "clean" fields within the same nursery. Moving diseased stock will introduce the disease and, once there, it is extremely difficult, if not impossible, to get rid of. Also, additional species of Phytophthora, not present previously, could be introduced into a nursery by contaminated stock. Similarly, equipment that has been in diseased fields, should be washed free of soil to prevent contamination of the next field it enters. This is very important for nurseries that borrow or trade equipment.

Resistance

Tree species vary in their susceptibility to Phytophthora root rot. True firs, western and mountain hemlock, and Douglas-fir are very susceptible to Phytophthora species found in PNW nurseries. Pine species, spruce, larch and incense cedar are moderately susceptible. Western redcedar is resistant. These groupings are based both on field observations and greenhouse pathogenicity tests. In areas of your nursery which are poorly drained, prone to flooding, or where Phytophthora root rot was present in the previous crop, resistant or tolerant species should be sown or transplanted. Very susceptible species should be planted in areas which are well-drained and, if possible, have not had a history of Phytophthora root rot.

CHEMICAL MANAGEMENT

Various fumigants and fungicides are available to control Phytophthora root rot.

Fumigants

Fumigants are general biocides which are used to treat fallow soil prior to sowing or transplanting. The fumigants methyl bromide-chloropicrin, vapam, and dazomet will reduce soil populations of Phytophthora spp. when used correctly. For nurseries with widespread, continuous problems with Phytophthora root rot and other soil-borne diseases, fumigants are an efficient and effective way to reduce disease levels. Phytophthora root rot has occurred in fumigated fields, however, due to re-introduction of the fungus, e.g., transplanting of already-diseased stock; use of contaminated water for irrigation; movement of contaminated soil during flooding or on equipment.

Fungicides

A number of fungicides are registered for use on conifer seedlings for control of Phytophthora and Pythium spp.:

1. metalaxyl (Subdue®, Ciba Geigy)
2. phosethyl Al (Aliette®, Rhone-Poulenc)
3. ethazole (Truban®, Mallinckrodt)
4. propamocarb HCl (Banol®, Tuco)
5. fenaminosulf (Lesan®, Mobay)
6. ethazole-methyl thiophanate (Banrot®, Mallinckrodt)

Use of fungicides can supplement cultural practices. They should not be depended upon to protect or cure seedlings, especially those that are in an environment that promotes disease, such as a wet, poorly drained field. We have sufficient data and experience to demonstrate the effectiveness of metalaxyl. The other fungicides have been used with success on other crops, but we have not yet been able to show their effectiveness on conifers against Phytophthora spp. There are a couple of reasons for this: There have been relatively few field trials in PNW conifer nurseries where the disease intensity has been high enough to conduct a meaningful test. Additionally, application techniques and timing, particularly with new products such as Aliette, have not been optimal so that the full potential of the fungicide has not been seen.

Metalaxyl is a systemic material which is taken up by the roots and moved acropetally (upwards and outwards) in the plant. It can be applied as a liquid onto the foliage and then watered into the root zone (Subdue 2E) or it can be incorporated as granules into the soil or onto the surface of the soil, with with release of the product occurring after watering (Subdue 5G). Once in the plant, metalaxyl inhibits further development of Phytophthora so that disease progression is halted. The fungus is not eradicated from the seedling, however. The consequences of non-eradication can be either minimal, such as when you out-plant a treated, but infected, seedling into a dry, well-drained forest environment, or quite severe, such as when you transplant a treated, but infected, seedling into a poorly drained portion of another nursery.

Metalaxyl should be used sparingly and thoughtfully since strains of Phytophthora, tolerant to metalaxyl, can become predominant in soils which have had repeated, frequent applications of the fungicide. Repeated use can also result in decreased effectiveness due to the build-up in the soil of microbes capable of degrading metalaxyl. Highly susceptible seedling species in high-risk areas (areas which are poorly drained, prone to flooding, or which have had disease in the previous crop) should have the first priority for treatment. One well-timed application of metalaxyl per year can adequately control Phytophthora root rot in most cases. Several applications in 1 year will give increasingly more benefit with each additional application, but each increase is very small and probably is not worth the additional application cost (Hamm et al. 1984). Application in the fall or spring prior to the development of symptoms will be the most effective. Timing of fungicide applications, as well as cultural activities, are discussed by Cooley et al. (1985) in greater detail.

Chlorination

In some locations, water supplies which are used for irrigation are contaminated with Phytophthora spp. Inoculum in the water can be eliminated or reduced to non-damaging levels by chlorination of the water before it enters the irrigation lines. We are still learning to adequately measure and interpret chlorine levels; for example, how much chlorine gas needs to be added to get 5 ppm free chlorine and how much free chlorine is required to reduce Phytophthora to undetectable levels in the water? Other factors, such as pH and the amount of organic material in the water, will also affect how chlorine reacts and how much is needed to kill propagules of Phytophthora.

Some sources of water are more likely than others to become contaminated with Phytophthora. Well-water and municipal water are probably more disease-free than water from open canals and agricultural districts. To determine if your water source is contaminated, Phytophthora can be detected by baiting. The baits are green fruit (of apple or pears, for example) which are placed in the water; spores of the fungus are attracted to the fruit and will enter it and cause decay. The fungus can then be isolated from the decayed tissue on a petri plate and identified.

In conclusion, I would urge all of you who have experienced Phytophthora root rot to keep at your drainage problems, continue to upgrade your field topography, be conscientious about coordinating your water uses and keep good histories of your fields so that you can plan where to sow or transplant your susceptible species. I urge you not to depend on fungicides; they are for emergencies, for marginal situations, not for routine applications. FORTUNATELY, because Phytophthora is very dependent on its environment, it can be very easily controlled with good cultural practices.

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Some Insect Pests of Conifer Seedlings in British Columbia[1]

Gwen Shrimpton[2]

Abstract.--Girdling damage to conifer seedlings caused by the Cranberry girdler, Crambus nevadellus, the European Marsh Crane fly and adult weevils is described. A monitoring program for fungus gnat populations in greenhouses is also discussed.

INTRODUCTION

Conifer seedling nurseries in British Columbia (B.C.) have sustained girdling damage from several insect pests. Criteria to differentiate the types of girdling have been compiled so that control programs can be readily implemented. This paper briefly outlines the insect girdlers found, describes the type of damage they do and discusses some control programs that have been developed in B.C. A program used to monitor populations of fungus gnats that occasionally become pests of container seedlings is also described.

INSECT GIRDLERS OF CONTAINER SEEDLINGS

The Cranberry girdler Chrysoteuchia topiaria was confirmed as a pest in B.C. in 1981. Pheromone trapping programs have determined its presence at all ministry nurseries in the province. To date damage has been confined almost exclusively to bare-root, 2+0, true firs and Douglas fir. Transplant stock, container stock and seedlings of other species are rarely affected. Damage is caused by the larvae that live in the duff layer at the surface of the soil. The larvae feed on stock from late August to mid-November. The solitary larvae appear to stay in one place long enough to feed on up to 5 seedlings and then move on for about 20 inches before feeding again. Damage generally occurs in scattered patches. The larvae eat the bark and chew into the wood, though the stem is not always completely ringed. The area, approximately one inch above and below the soil line, is attacked; some chewing may be found on the upper roots. An excellent control program using phermone traps has been developed for this pest (Triebwasser & Overhulser, 1980).

In 1985 and 1986 another small moth Crambus nevadullus, a relative of the cranberry girdler, was found girdling container seedlings at two nurseries in the Okanagan. Damage appears as a uniform ring about ¼-½ inch wide just at soil line. It resembles adult root weevil damage, but fine silk webbing is often seen at the surface of the plug and larvae may be found near the damaged seedling. To date, damage has occurred during the month of August and only spruce seedlings have been attacked. Damage is distributed in small pockets of 1-7 seedlings throughout the greenhouses. Moths of this species have been caught in low numbers in cranberry girdler phermone traps for a number of years and their life histories are similar.

The European Marsh Crane fly Tipula paludosa has been a chronic pest at several coastal nurseries for the past ten years. Girdling caused by the soil dwelling larvae occurs from March to May. Any stock present at the nursery during this time can be attacked. To date, most damage has occurred in bare-root stock, where there seems to be no host preference. The damage consists of a uniform ring about one inch wide just at soil line. The stem is nearly always completely ringed and only the bark is consumed. Some of the upper roots may also be stripped. Damage has a spotty distribution with small patches of 1-7 seedlings attacked throughout an infested area. Each patch is generally the work of one larva which is often found with the damage.

Several species of adult weevils have been confirmed or are suspected to girdle conifers in greenhouses. Adults of three root weevils Otiorhynchus ovatus the strawberry root weevil, O. rugosostriotus the rough strawberry root weevil and O. sulcatus the black vine weevil have been observed feeding on seedlings.

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[1] Paper presented at the Western Forest Nursery Council Meeting, Tumwater, Washington, August 12-15, 1986.

[2] Surrey Nursery, Surrey, British Columbia.

Adults of Trachyphloeus bifoveolatus the small grey grass weevil and Strophosoma melanogrammum have been observed in sufficient numbers where damage has occurred to suspect them as the cause.

Girdling consists of a uniform little ring about ¼" wide, often just below the point at which foliage begins in the fleshiest part of the stem. Damage usually occurs in June and July. Weevils seem to attack seedlings for a limited period of time when enough bark tissue has developed for them to feed, but before the stems have become too woody. Most girdled seedlings are between 3½ and 6 inches in height. Seedlings at the edges of the greenhouses and ones on the outsides of the styroblocks are attacked most frequently. Usually only one seedling is girdled at a time. There appears to be a preference for spruce, however cedar, larch, fir and pine have also been attacked.

Adult root weevils are elusive, feeding at night and hiding during the day. As a result, populations usually go undetected until damage occurs. Monitoring programs have been attemped at several nurseries. Weevil boards, bait stations, pitfall traps, indicator plants such as rhododendrons and sticky traps have all been tried without success.

A control program to reduce girdling by adult weevils using Pydrin (fenvalerate) has been developed and was successfully implemented at one nursery in 1986. The timing of the applications is critical for effective control. Adult weevils emerge when the weather becomes warm in the spring around the middle of May. This is also the time when the seedlings have reached a susceptible stage. Pydrin is applied as a foliar spray during the second week of May, and this is followed by a second application 3 weeks later. It appears that the insecticide acts more as a repellant than as an insecticide. These insects have a large host range and will move on to feed on plants in a more favourable environment.

SMALL FLY POPULATIONS IN GREENHOUSE FACILITIES

Many nurseries in B.C., especially the older established greenhouse facilities, have large populations of small flies. In 1981 and 1982, adult and larval flies were collected from seven nurseries and eleven different families were identified (table 1). Of these the shore flies family Ephydridae were the most common. These insects breed in algae and decaying matter in wet areas and are not nursery pests. Occasionally, however, populations of fungus gnats family Sciaridae have been observed damaging container seedlings. The larvae infest the plugs feeding on the upper roots, and in heavy infestations, they can girdle the stems just below and at soil line. Infestations of fungus gnats are not common and the seedlings attacked have usually been predisposed, often by an infection of Fusarium. Once the seedlings are well established and vigorously growing, these insects are generally not pests.

Table 1.--Families of small flies collected in container facilities.

Agromyzidae
Anthomyiidae
Cecidomyiidae
Chironomidae
Dolichopodidae
Empididae
Ephydridae
Muscidae
Psychodidae
Sciaridae
Sphaeroceridae

In 1986, a monitoring program for populations of small flies was conducted at 4 nurseries in B.C. Yellow sticky ribbons were hung throughout the greenhouses. Yellow is a color that attracts many species of insects which then become stuck to the surface of the ribbon.

The purpose of the program, was to monitor the populations of insects present, and to train nursery personnel to distinguish between the innocuous shore flies and the potentially damaging fungus gnats using the characteristics in table 2. The second purpose was to actually reduce the numbers of flies present in the greenhouses. Although many of the flies present are not directly damaging to the stock, large swarms can be annoying to nursery workers. In cucumber greenhouses, growers have successfully reduced fly populations using these yellow sticky ribbons at a density of one every ten square feet.

Insect girdlers generally are not major pests of conifer seedlings. However, effective control programs can be developed once characteristics have been determined to differentiate the various types of girdling. Fungus gnats can occasionally become pests on the nurseries but the majority of the flies present will not feed on conifer stock and are only a problem because of their nuisance value.

Table 2.-- Characteristics used to differentiate shore flies and fungus gnats.

	Shore Flies	Fungus Gnats
Family	Ephydridae	Sciaridae
Body	size and shape of fruit flies	resemble tiny mosquitoes
Size	2 - 4 mm	2 - 4 mm
Wings	have pale spots	grey with "Y" shaped vein
Antennae	short with a bristle	long bead-like
Flight	tend not to fly but are strong fliers when they do	easily excited into flight but are poor fliers
Larvae	maggots have no distinct head	maggots are slender with dark shiny heads

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Triebwasser, Mark E., and David C. Overhulser. 1980. The cranberry girdler in conifer nurseries of Western Washington and Oregon. Proceedings Intermountain Nurseryman's Assoc., Western Forest Nursery Council, Joint Meeting, Boise, Idaho, August 12 - 13, 1980.

Reducing *Fusarium* Top Blight in 1-0 Douglas-fir by Irrigation Scheduling[1]

Kenelm W. Russell[2]

Abstract.-- Dry Pacific Northwest summer weather is when one phase of Top Blight caused by Fusarium spp. infects 1-0 forest nursery seedlings. Top Blight appears when nurseries use short cycle cooling irrigation during hot weather. Infection is prevented by deep watering up to one inch at infrequent intervals.

MIDSUMMER CRISIS

Time: Monday, August 4, 1986
Place: Department of Natural Resources
Pathology Lab south of Olympia, Wa.

1100 Phone call. Anxious nursery reports dying 1-0 DF seedlings. Bill (grower) on vacation. Trees sprayed weekly- 8 oz./ac captan/benomyl mix. No rain for 26 days. Weather- HOT! Short cycle cooling irrigation schedule being followed.

"Uh oh! I'd better get right over!"

1130 I arrive at nursery. Found 1-0 DF seedlings wilting, yellowing, and finally red.

No evidence of fungus anywhere on seedlings.

Soil moist in top inch- dry below that. Seedlings appear stressed.

Initial diagnosis- Fusarium Top Blight.

Action: Recommended immediate deep watering to relieve stress on seedlings. Fungicides NOT needed now.

1300 Spent PM looking through microscope for sign of fungus. Nothing!

Deep watering in progress at nursery.

1700 Placed dozen seedlings in plastic bag with wet paper towel to keep them moist. Left them on counter and went home.

0800 Tuesday. Seedlings in moist chamber bag fluffy white with fungus mycelium.

0815 Placed a bit of the mycelium from the root crown area on a glass slide, added a drop of lactophenol/cotton blue stain and a cover slip. Under the microscope at 100 power, I found thousands of Fusarium species macrospores. Their cellular banana shape with several cross walls were a dead giveaway.

0817 Top Blight confirmed. Nursery notified and advised that mortality will taper off as stress on seedlings decreases.

1200 Deep watering (one inch) in progress. After an inch, no water will be added until soil dries to just above seedling stress point. Short cycle cooling irrigation stopped.

INTRODUCTION

The most common midsummer disease in Pacific Northwest forest nurseries is Top Blight. Conifer seedlings are most susceptible to infection in their first growing season. Outbreaks can often be tied back to water stress or improper nutrient application. One or more Fusarium species are involved and other fungi have been isolated from Top Blight symptom trees as well (Hamm 1986).

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[1] Paper presented at the Western Forest Nursery Council Meeting, Tyee Motor Inn, Tumwater, Wa. August 12-15, 1986.

[2] Forest Pathologist, Washington State Department of Natural Resources. Olympia, Wa.

Many years ago on a hot summer day approaching July 4th, Bill Fangen and I were trying to figure out what was killing the 1-0 Douglas-fir seedlings in the Washington State Department of Natural Resources Webster Nursery a few miles south of Olympia. Once again, just as in the crisis situation above, then nursery manager, the late Red Ward, was on a trip to Japan.

Our timing for looking was perfect as we caught the fungus (Fusarium spp) with its pants down and I was able to identify it immediately under the microscope. I found masses of spores in crust like fungal mats near the root crowns of droopy yellow and red colored seedlings. The numerous banana shaped macrospores were easy to identify.

The nursery was then in a cooling irrigation mode. I remember saying, "Bill, these seedlings look stressed. We need to get some heavy water to them right now."

When Red arrived home, Top Blight was under control and the seedlings were one-third taller. The nursery looked beautiful.

I've since nicknamed this summer seedling malady the "Fourth of July Disease" because it coincides with the onset of the hot dry summer weather which often arrives west of the Cascade Mountains just before or after the holiday.

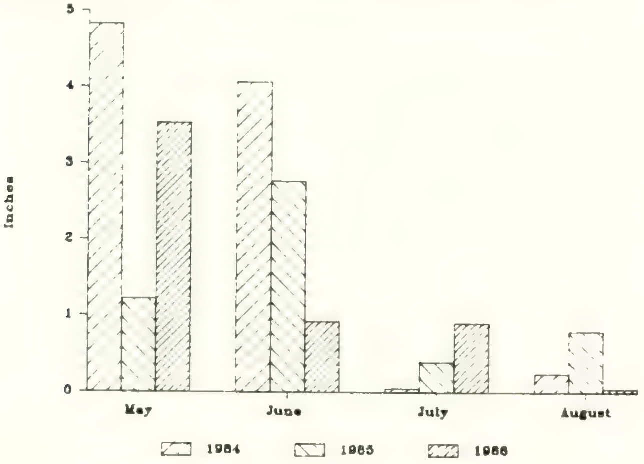

Figure 1.--No rain in late summer, 1986 saw ideal Top Blight conditions at Webster Nursery. The 1985 summer rain was more evenly spaced and Top Blight was reduced.

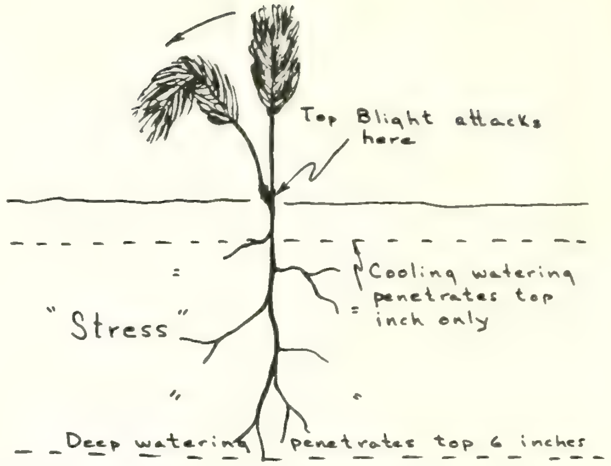
Top Blight attacks here
Cooling watering penetrates top inch only
"Stress"
Deep watering penetrates top 6 inches

Figure 2.--Summer Top Blight incubates in warm, moist upper soil and attacks at the root crown when seedlings are stressed.

Top Blight as described above does not appear to be a serious problem during wet summers, or summers where rainfall is periodic. The most probable reason is that seedlings are not stressed as much as they could be during a long hot summer. Research needs to explore this.

TOP BLIGHT BUILD UP CONDITIONS

Warm weather, summer rainfall (both amount and timing), irrigation scheduling, and nitrogen availability are key ingredients that determine potential for infection. Summmer, 1986 saw a higher than normal incidence of Top Blight in several nurseries. It turned hot and dry in July and no rain fell from July 11 until September 8 (fig. 1).

Trouble from Top Blight builds during the hottest part of the summer when rain is absent and trees are watered on a short daily schedule for cooling. This irrigation pattern cools and wets the top inch or so of soil but little water reaches the main moisture absorbing part of the root system two to five inches lower.

The seedlings become stressed and infection is triggered. They wilt, gradually fading to yellow, then red (fig. 2). Mortality is not great at first, but red trees scattered intermittently along the rows appear alarming. If left unchecked Top Blight could severely deplete the seedling beds. The fungus tends to build up in the warm, moist upper soil layer created by the frequent, short cycle cooling irrigation. The warmer the weather, and the longer the interval between prolonged rains, the higher the chances for infection. The tender seedling stems are set up for attack just above the root crown.

Check lower root zone soil moisture in your own nursery on a hot summer day after you have been watering on short cooling cycles. Dig through the top eight inches of a 1-0 seedbed and look for dry soil lower than one inch from the surface. If the lower soil is dry the stage may be set for Top Blight infection.

TOP BLIGHT PREVENTION

Prevention of Top Blight means anticipating infection when the weather looks like it will favor the disease. Be ready with prevention techniques when the stable summer high enters the Pacific Northwest.

After a week of hot, dry weather use an infrequent deep watering schedule equivalent to at least an inch of rain at a time. CREATE YOUR OWN SUMMER RAINSTORMS ON YOUR OWN SCHEDULE. You don't even have to have the clouds! Repeat this schedule until rain appears.

This kind of watering is the heart of Top Blight prevention. It takes courage to hold to it when the soil heats up. Under some conditions, seedbeds may need to be cooled. Use your judgment to decide when to water based on knowledge of your soil's moisture holding capacity.

Preventive fungicide applications must be timed to prevent loss or movement of active ingredient from the target tree. A regular fungicide schedule will help reduce or prevent infection, provided it is not washed off the target tree during watering or rain. This is what may have happened in the crisis situations described at the front of the paper.

Fungicide applications must be flexible so they can be changed if rain is on the way. Fungicides must be applied after watering or rain to avoid washing them away before they can be absorbed into plant tissues or otherwise activated. Preventive applications should include alternate fungicides so that no one fungus gets the upper hand.

Summer applications of nitrogen have been shown to favor incidence of various Fusarium species. Minimize mid summer applications of nitrogen fertilizers.

CONTROLLING TOP BLIGHT

If you are caught with an outbreak and if it is confirmed in similar fashion to my description above, control it at first with water. Add at least one inch to relieve seedling stress and then and only then, apply a fungicide. Fungicides seem to do little good until seedling stress is relieved.

HOW TO IDENTIFY FUSARIUM TOP BLIGHT

If your Top Blight Integrated Pest Management techniques are working during the hot months you should not see enough infection to worry about. In the event the weather brings on a problem despite your best efforts, here is how you can identify the disease on suspected seedlings.

In first year seedbeds look for drooping yellow-green, then yellow and finally red seedlings scattered intermittently along the rows. When you dig the seedlings, the lower roots appear to be healthy. The area immediately above the root crown is dead and the tops are limp. Observe root crown areas carefully for presence of crusty looking whitish mats of mycelium. A 10x hand lens can be used in the field. If fungus mycelium is found you need to place a scraping of this material under the microscope to look for the distinctive macrospores.

If fungal growth of any kind is absent place a dozen seedlings in a plastic bag along with a small piece of wet paper toweling to provide a moist chamber.

Leave the seedlings at room temperature overnight or as long as it takes to allow fungus mycelium to grow out of the lower seedling stems. Usually, the fungus grows out overnight and can be observed the next day.

Place a bit of the mycelium on a clean slide with a small knife or scalpel. Add a drop of lactophenol/cotton blue for staining, then carefully drop a cover slip in place, and observe under 100 to 400x (fig. 3). Microscope power is determined by multiplying the numbers in each lens together. For example, 10x eyepieces times the 10x objective lens equals 100x Usually, this is sufficient magnification to positively identify Fusarium species macrospores. You will need help from a pathologist to identify Fusarium to individual species.

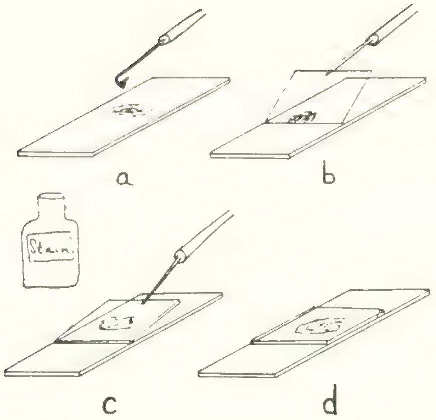

Figure 3.--Place strands of fungus growing on seedlings in the moist chamber bag on a slide and add one drop of stain (a). Place cover slip gently to avoid bubbles (b-d). Observe under microscope at 100x.

Fusarium species have three kinds of spores, macro, micro and chlamedospores. Look for the distinctive banana shaped macrospores which are about two to four times longer than the small rather nondescript microspores (fig. 4). Chlamedospores would not normally be found on a newly killed seedling because they are a type of resting spore and do not appear until later stages of growth.

The suggestions above are meant to help you get quickly on top of a problem. I recommend a call to your neighborhood pathologist to confirm your diagnosis and look into any subtle conditions of the infection pattern that might be peculiar to your nursery. Top Blight varies a little from nursery to nursery.

BALANCING TOP BLIGHT PREVENTION WITH HARDENING OFF

Infrequent, deep watering to minimize Top Blight infection could be a problem if it is late in the growing season. The grower wishes to slowly harden the seedlings off to force dormancy. This is usually done by withholding water and nutrients. Growers walk a tight wire between creating disease development conditions and hardening off.

Personally, I would rather irrigate on the deep, infrequent pattern in hot July and August to minimize infection potential when seedlings are still tender. Then, I would harden the seedlings off when weather is unfavorable for Top Blight and they have more natural infection resistance.

Irrigation schedules may be so inflexible that they do not allow human judgment while actually watering. Valves simply get turned on and off for a specified number of minutes without close looks at the trees. This is where green thumb gardening pays off in disease prevention.

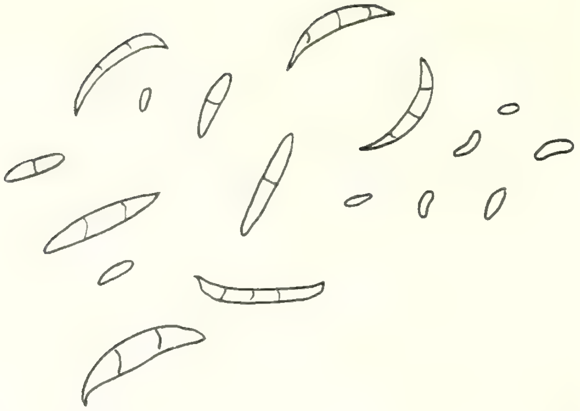

Figure 4.--Distinctive Fusarium spp. macrospores under the microscope at 100x are banana shaped with 2 to 3 crosswalls. Microspores are small bean shaped and may or may not have crosswalls.

Persons with watering responsibilities do better when they combine green thumb gardening experience with the rigid scheduling. Practiced gardeners often have a natural tendency to closely observe what the plants and outside agents (disease) are doing and may strike good balance between watering, disease development and dormancy inducement. This natural gardening attitude can be a helpful factor in helping to minimize disease.

Growers, irrigation managers, and their helpers should be carefully trained (1) to recognize Top Blight build-up conditions (2) to apply prevention techniques when weather and conditions favor infection, and (3) to recognize and treat the actual disease. I've seen some excellent results when growers follow these principles of Integrated Pest Management.

Don't feel bad if this critter pops up in your nursery once in a while. The summer of 1986 was nice for recreating and outdoor enjoyment, but it was a heck of a year for the "Fourth of July" disease.

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Hamm, P.B. 1986. Top Blight Disease Complex. Presented at Western Forest Nursery Council Meeting, Tyee Motor Inn, Tumwater, Washington, August 12-15, 1986.

Options in Controlling Soilborne Pests[1]

Fred D. McElroy[2]

My purpose in selecting this topic for presentation is two-fold. First, it serves as an excellent prologue to our fumigation studies, which will be presented next. Second, and most importantly, I hope that it will stimulate some reevaluation of the subject of soil fumigation. This process of reconsideration is addressed both to nurserymen and researchers.

WHY THE CONCERN?

The first concern is the possible loss of registration of presently used soil fumigants. It may take anywhere from 1-5 years, but when it occurs it could happen quickly as it has in the past. The continued increase in technology of detecting chemicals in the environment, and the continued concern for environmental contamination suggests that it's only a matter of time.

Working out alternatives to presently used pesticides involves considerable time and money. We should be in the positive position of having a replacement waiting in the wings and ready to go as soon as the primary pesticide is lost.

Another concern is that the most common presently used fumigant is a biocide, which is hazardous to both humans and the environment. Again, with the increased pressure to reduce the use of these soil sterilants, it may only be a matter of time before pressure is brought to bare in this area.

The other problem with this presently used fumigant is the high cost. Soil fumigation is presently the most costly soil management activity conducted in a nursery. With the downturn in the forest nursery economy, and competition increases, those nurseries that can keep their cost of production down will be the most competitive.

Soil fumigation in forest nurseries using Methyl bromide-chloropicrin, is overkill. Many times the rates are too high and the biocidal activity of the chemical is too broad spectrum. This results in destroying both the beneficial and pathogenic organisms. It's rather like using a nuclear weapon to stop a riot. We have difficulty sorting out the good guys from the bad guys and so we kill everyone. This always results in a loss of a lot of innocent bystanders, and in this case, these are the beneficial soil organisms. Container nurserymen have learned the difference between pasturization and sterilization of the soil, but it's a lesson yet to be understood and learned by bareroot nurserymen.

Ironically, however, even with sterilization many 1-0 crops routinely experience a certain percent mortality each year from damping-off and lower stem canker diseases. Even if soil treatment is effective at sowing, its effect is gone soon after sowing. This suggests there may be a better way of dealing with this short-term problem.

More judicious use of the presently used pesticides may delay their loss from registration. If it can be demonstrated that these materials are used only under necessary conditions, and then with the consideration of environmental protection, they are less likely to be lost from registration.

Finally, a time may be approaching when future regulations may require a prescription prior to the application of a soil treatment. This has already been tried for several pesticides in some states. While it has created many problems, there may be some instances in which it's justified. In the case of irreparable changes in the environment as a result of the application of a pesticide, a more thorough evaluation of that environment may be necessary prior to the application of such a pesticide. This may require laboratory tests to determine several things about the environment in order to evaluate what impact this treatment may have. These might include an evaluation of the soil microorganisms, soil type, geology and hydrology of the area, etc. Then a pesticide would be recommended which would be least damaging under these circumstances (Holden, 1986).

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[1] Paper presented at Western Forest Nursery Council Meeting, Tumwater, WA, Aug. 12-15, 1986.

[2] Fred D. McElroy, Ph.D., Owner/Director, Peninsu-Lab, Box 3000, Kingston, WA 98346.

Presently law suits involving groundwater contamination are in progress throughout the United States. Growers that have been most successful in defending their actions have had records of laboratory analyses to determine the need for fumigation. Many of these cases date back to the late 1970's and early 1980's before groundwater contamination was known to be a problem. Therefore, it's possible that at some future date nurserymen could be sued for the use of registered hazardous chemicals in the soil environment even though they are presently legal. These are very complex issues. A lot of innocent growers are being hurt in this sorting-out process. We, therefore, need to be forewarned about such issues and be taking some steps now to protect ourselves.

WHAT ARE OUR OPTIONS?

The use of crop rotation and/or fallow has controlled soilborne pests on a wide range of crops. This practice is currently being used on a number of agricultural crops as an effective management tool. Tests are presently being conducted by researchers at Oregon State University to evaluate this as a management practice in forest nurseries. This is a positive step forward and needs to not only be encouraged by the nurserymen, but they should actively be involved in some testing on their own.

There is a need to get away from overkill, and to apply pesticides against the specific target organisms. This, of course, requires determining what those target organisms are and developing control measures specifically against those organisms. More research is needed in this area.

Seed protection is another approach in controlling seed and soilborne pests. Even if soil treatments correct the problems in the soil, they are frequently reintroduced on contaminated seed. Occasionally a more severe problem is created by planting fungus infected seed in a relatively sterile soil environment. The beneficial organisms have been removed from the soil, and thus the fungus introduced on the seed has nothing to keep it in check and frequently creates more loss than if the soil had not been sterilized.

The use of biological control agents is another area which has not been fully explored in the forest nursery industry. There have been several breakthroughs in the use of beneficial fungi and bacteria for controlling soilborne agricultural pests. These are applied either as seed treatments or soil amendments (Cook & Baker, 1983).

In the final analysis, alternatives to biocidal soil fumigation will probably involve a combination of the above practices. The exact combination will be determined by the nurseryman's unique set of conditions and needs. There are probably also other practices which may be beneficial, but have not been fully evaluated or enumerated at this point.

PREDICTIVE EVALUATIONS

As was mentioned earlier, in order to avoid the "biocidal-overkill" approach we have to be able to sort out the "good guys" from the "bad guys". Having made that determination we can then select the correct weapon for the job. Below I have selected the areas I believe we need to be concerned about and discuss them in terms of our present knowledge and our future needs.

Soilborne Microorganism Assay

In terms of predictive assays, we probably have the greatest knowledge about nematodes. Preplant nematode assays have been used for several decades to determine soil treatment needs (Taylor, 1971, Oostenbrink, 1972). Procedures are more or less standardized and many government as well as private laboratories routinely conduct nematode assays for growers.

Routine assays for soil fungi (e.g. Fusarium, Pythium, Rhizoctonia, Phytophthora, etc.) appear to still be in developmental stages, although the technology has been available for several years. Several assays are presently being used for agricultural crops, but these too are limited.

The precedent for use of soilborne assays in forest nurseries was set several years ago. The Canadian Forest Service in British Columbia routinely analyzes proposed sowing blocks for soilborne fungi. Since Methyl bromide-chloropicrin is not registered for use in British Columbia, soil showing high levels of Pythium and Fusarium are taken out of production and alternative sowing areas are sought. Population reduction is accomplished by bare fallowing for one year.

The Department of Natural Resources Nursery in Olympia, Washington uses a similar technique to determine need in proposed sowing blocks (Russell, 1976). The registration of Methyl bromide-chloropicrin in Washington provides soil fumigation of heavily infested soils as an additional option.

Peninsu-Lab was the first, and still is, the only commercial laboratory offering this service to Pacific Northwest Nurserymen. Cooperative tests with Peninsu-Lab, Canadian Forest Service, B.C., Department of Natural Resources, Olympia, Wa., U.S. Forest Service, Portland, Or., and Oregon State University, Corvallis, Or. has established the accuracy and reproducability of these tests.

Two of the weak links in the present program are an understanding of population dynamics of the fungi throughout the year, and an ability to interpret the results in different situations. Our findings over the years have suggested that the interpretation is best done on an individual nursery basis, avoiding generalities between nurseries. Unique conditions within a nursery influence the amount of damage caused by a certain population of soil fungi. The presence of certain soilborne biological antagonists probably play a major role in this variation. At the present time there is very little understanding of what these organisms are, and their importance in the nursery situation. A better understanding of these beneficial organisms will enable us to improve our interpretation. Also with a better understanding of these organisms, we may be able to reintroduce them into the soil following treatment to regain a more balanced soil microorganism population.

Seed Asaays

Another predictive tool which would be useful would be the assay of each seed lot for seedborne fungi. Pathogens such as Fusarium are frequently found both externally and internally associated with seeds, which in turn influences the amount of loss experienced by the nurserymen. If a seedlot is found to be heavily contaminated with Fusarium and cannot be cleaned up, less disease loss may be experienced by planting into a nonfumigated soil rather than into a sterilized environment. Also a knowledge of whether the fungus is internal or external will determine the efficacy of surface seed disinfection. From a research standpoint we need more information regarding the affect of the various fungi that are found on seed as well as more adequate means of treating the seed to control these organisms.

Weed Surveys

This is something the nurserymen can and should be doing routinely. Armed with the knowledge of weed species present in a particular block in the nursery, the nurserymen can then make a decision as to whether or not effective herbicides are available for their control or whether a biocide treatment is necessary. Often judicious use of selective herbicides is less costly than the soil fumigation.

Soil Insect Surveys

Soil insects are not ususally a major problem in forest nurseries. They do, however, occur on occasion and can be quite damaging. The White Grub of the Tenlined June Beetle is a good example. However, if proper surveys are conducted ahead of time the least costly control measure can be applied.

ADVANTAGES

There are several advantages in using predictive evaluations to determine the need for soil fumigation. First it allows us to target the organism to be controlled. We can then select a control measure specific for that organism. If a pesticide is required, the population level will enable us to determine the proper rate necessary for control. At the present time we are aiming for 100% control, whereas proper pest management techniques suggest that it is most beneficial to just bring the populations back into balance with the beneficial microorganisms in the soil.

This type of an approach also optimizes the per acre cost for treatment. In other words, the nurseryman applies just the pesticide needed at the proper rate to bring things back into balance, which enables him to produce the healthiest seedling with a minimum input of expense.

Finally, this approach becomes the prescription which may some day be required by government regulation. The pest population has been determined by field observation and laboratory analysis, a pesticide and rate and/or management technique has been selected to minimize the effect of the pest, optimize growth of the seedling, with minimal affect on the environment.

It may seem that we are a long way from such an ideal situation. However, I believe we are closer than many of us realize. Much of the technology is already available and simply needs to be put together and tested at the field level. I believe this can be accomplished in a relatively short time through the cooperative efforts of nurserymen, researchers, and private industry. It is not necessary for the nurseryman to wait until all the answers have been provided at the research level. Some of these tests can be conducted at the nursery level, and in fact, each nurseryman will eventually have to conduct these tests at their nurseries to determine what will and will not work.

My challenge, therefore, is to consider some of the options I have outlined, think of some of your own, take the initiative and act now rather than react when your number of options are more limited.

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Use of Metam-Sodium and Dazomet Fumigants[1]

Fred D. McElroy[2]

Controlling disease causing microorganisms in the soil environment prior to seed sowing is a difficult task. When a chemical is used for this purpose it must not only be capable of killing the organisms, but also be able to penetrate areas where those organisms are, remain there long enough to be effective, and leave the soil without a residual which might damage subsequently planted seed.

A number of soil fumigants have been used for this purpose over the years. In the last decade Methyl bromide-chloropicrin has become the standard since it very effectively meets the above criteria. However, it also has several disadvantages (e.g. cost, overkill, handling danger, etc.) as discussed in my previous talk on "Options in Controlling Soilborne Pests".

Peninsu-Lab is continually investigating new methods for dealing with soilborne pest problems, and as a part of this program has tested a number of soil fumigants. Over the last three years two of these chemicals tested under contract by Peninsu-Lab, have shown promise for use in forest nurseries. These compounds are Metam-sodium (Vapam, Soil-Prep) and Dazomet (Basamid-Granular).

With some minor differences, both compounds form the active ingredient Methyl isothiocyanate (MIT) when in contact with moist soil. This gas diffuses through the soil pore spaces moving mainly upward, killing the living organisms with which it comes into contact. This substance has a broad spectrum of activity against soil organisms such as insects, fungi, nematodes, and weeds.

Because of the differences in formulation, the two chemicals are applied by different means. Dazomet is a fine white granular material which is applied to the soil surface by means of a shaker, Gandy, or similar applicator. It is then tilled into the soil with a cultivator or hoe, and the soil surface sealed by compacting and irrigating.

Metam-sodium is a liquid and is applied through the irrigation system. The chemical is applied in about an inch of water and must be metered in during the entire time of irrigation (5-6 hours).

In comparison, Methyl bromide-chloropicrin is a gas which is injected into the soil to a depth of about 8-10" using shanks drawn behind a tractor. The soil must immediately be sealed with a polyethylene tarp to prevent rapid escape from the soil.

With all of these chemicals the soil must be tilled 1-2 weeks after treatment to allow escape of the gas prior to planting. This time interval is determined by a number of factors such as chemical, temperature, moisture, etc.

The following summarizes our findings over the past three years in several nurseries, and presents data from the 1985-86 tests. In all studies with Dazomet and Metam-sodium, Basamid-Granular and Soil-Prep respectively were the commercial products used.

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[1] Paper presented at Western Forest Nursery Council Meeting, Tumwater, WA, Aug. 12-15, 1986.

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1984 - Spring Application

At nursery A, Dazomet, Metam-sodium, and MC-33 were applied at 531, 100 and 350 lbs. per acre (ppa) respectively. Pre-treatment populations of Pythium and Fusarium were low and were significantly and equally reduced by all treatments. Because of the low population of soilborne fungi there was no significant difference in damping-off amongst the plots.

Based on paired sampling studies conducted by Peninsu-Lab of several nursery soils containing healthy and diseased seedlings, we consider populations of Fusarium and Pythium in excess of 1000 and 100 propagules per gram (ppg) of soil to be potentially damaging to conifer seedlings.

Approximately 1" of rain fell 3 days after treatment with Dazomet, which resulted in moving the material deep into the soil profile. The chemical did not escape from the soil until after sowing, resulting in phytotoxicity to the seedlings.

In nursery B, Dazomet at 350 ppa was compared to MC-33 at 350 ppa. In this nursery Fusarium, Pythium, Phytophthora, and 5 genera of plant parasitic nematodes were present in moderate to high populations. MC-33 and Dazomet reduced soil fungus populations by 88% and 70% respectively, which were both significantly below the untreated plots. Both treatments eliminated all nematode genera. Damping-off in the Dazomet treated plots was 1.8% compared to 12% in the untreated. A combination of a lower rate of Dazomet and minimal rainfall following treatment resulted in no phytotoxicity in these plots.

1985 STUDIES

Dazomet Rate Study - No Sowing

Dazomet was tested as a spring application at 0, 95, 187, 267, and 367 ppa. The material was applied operationally using a Gandy 1-bed (4') drop spreader, immediately tilled to 8", rolled with a bed roller and irrigated. Soil fungus populations and weed growth were evaluated and are shown in Tables 1-3.

The three highest rates all reduced both Pythium and Fusarium populations significantly below the untreated plots. Given the initial soil populations and the time of year, the 187 ppa rate would have been sufficient to reduce populations below damaging levels. All rates reduced weed populations significantly below the untreated controls. There was little difference between the 95 and 187 ppa rates, and between the 267 and 367 ppa rates.

For forest nurseries, it appears that a rate of 267 ppa may be as effective in reducing fungus populations as higher rates. It may even be possible to reduce this rate to near 187 ppa and still obtain adequate control. While weed control at 95 and 187 ppa was not as good as the two higher rates, it was significantly better than the untreated and may be adequate for a nursery program.

Dazomet Rate Study - No Post Treatment Herbicides, No Sowing

To determine the effectiveness of Dazomet alone in controlling weeds, 2 rates of material were applied with no post treatment herbicides.

Both rates of Dazomet gave good soil fungus control (Table 4) and weed control (Table 5). Although weed control was significantly better in the treated plots 4 weeks after sowing, by 6 weeks all plots were heavily infested with weeds. This demonstrated that while Dazomet is effective in significantly reducing weed seed populations in the soil, the standard nursery practice of applying a pre-emergence herbicide (such as Goal) is essential. Dazomet reduces the total weed population to a more manageable level using the pre-emergence herbicides.

1985-86 STUDIES

A series of tests were set up at each of four nurseries comparing differenct rates of Dazomet with other soil treatments. Two rates of Dazomet were selected for each nursery based on pretreatment soil fungus populations in that nursery. This was an attempt to determine if the level of soil fungus populations within a nursery could be used to select the lowest effective rate of Dazomet.

TABLE 1.--EFFECT OF 5 RATES OF BASAMID-GRANULAR ON FUSARIUM SOIL POPULATIONS - NURSERY A

TREATMENT (ppa)*	FUSARIUM (ppg)** PRE TREAT	FUSARIUM (ppg)** POST TREAT	% CHANGE
0	1833	1075	41.4
95	1674	684	59.1
187	1193	51	95.7
267	1209	193	84.0
367	1259	0	100

Values are an average of 3 replications
*ppa = pounds/acre
**propagules/gram of soil

TABLE 2.--EFFECT OF 5 RATES OF BASAMID-GRANULAR ON PYTHIUM SOIL POPULATIONS - NURSERY A

TREATMENT (ppa)*	PYTHIUM (ppg)** PRE TREAT	PYTHIUM (ppg)** POST TREAT	% CHANGE
0	87	178	+104.6
95	82	102	+24.4
187	371	38	89.8
267	33	0	100
367	119	0	100

Values are an average of 3 replications
*ppa = pounds/acre
**propagules/gram of soil

TABLE 3.--EFFECT OF 5 RATES OF BASAMID-GRANULAR ON WEED POPULATION 5 WEEKS FOLLOWING TREATMENT - NURSERY A

TREATMENT(ppa)*	TOTAL WEEDS/50' BED
0	50
95	17
187	14
267	1
367	1

Values are an average of 3 replications
*ppa = pounds/acre

TABLE 4.--EFFECT OF BASAMID-GRANULAR ON SOIL POPULATIONS OF FUSARIUM AND PYTHIUM - NURSERY A

TREATMENT (ppa)*	PRE TREAT**		POST TREAT	
	FU	PY	FU	PY
0	1000+	213	1000+	100+
267	1000+	147	44	0
490	1000+	100	4	0

Values are an average of 3 replications measured in propagules/gram of soil.
*ppa = pounds/acre
**FU = Fusarium, PY = Pythium

TABLE 5.--EFFECT OF BASAMID-GRANULAR ON WEED POPULATIONS 12 WEEKS FOLLOWING TREATMENT - NURSERY A

TREATMENT (ppa)*	WEEDS/1 FT. OF BED**				
	TOTAL	CHK	COT	GRASS	OTHER
0	826	808	3	12	3
267	19	15	4	0	0
490	12	7	5	0	0

Values are an average of 3 replications
*ppa = pounds/acre
**Chk = untreated, Cot = cottonwood, Other = unidentified weeds

Soil fungus populations were evaluated in mid September of 1985, and treatments applied in late September or early October of the same year. Post-treatment soil fungus evaluations were made in late October of that year, and March and June of 1986. Seed was sown into the plots in May of 1986. Results from the various nurseries are shown below.

Nursery A

Treatments at this nursery consisted of MC-33 (350 ppa), Vorlex (35 gpa), Dazomet (150 and 300 ppa), and an untreated check. Fusarium populations (Table 6) declined significantly for all chemical treatments. Populations in all plots, including the untreated check, continued to decline until March of 1986. By June all populations had risen slightly, but all chemical treatments remained below the untreated check. Also, all remained below the damage threshold level of 1,000 ppg.

MC-33 gave the best control, followed by Vorlex, Dazomet 300, Dazomet 150, and untreated check. Pythium populations followed a similar pattern.

There was no significant difference in number of live seedlings or damping-off in any of the treatments. This correlates well with the soil populations of Fusarium and Pythium, all of which were below threshold levels at time of sowing. While all chemical treatments reduced soil fungus populations, soil treatment of any kind was probably not justified at this nursery.

Nursery B

Dazomet was applied at three rates (0, 250, and 300 ppa), applied as the only treatment at this nursery. A procedure similar to nursery A was followed here. Similar declines in soil fungus populations (Table 8) were observed at this nursery in the 250 and 300 ppa Dazomet plots.

By spring, populations of both Pythium and Fusarium in all treatments had declined to below threshold levels. As a result there was no significant difference in number of live seedlings or mortality.

Nursery C

Treatments at this nursery consisted of MC-33 (325 ppa), Metam-sodium (100 gpa), Telone II (30 gpa), Dazomet (150 and 300 ppa), and an untreated check. All chemical treatments reduced soil fungus and nematode populations below the untreated check (Tables 9, 10, and 11).

Telone II and Metam-sodium were not originally included in this test, so pretreatment samples were not collected. However, these treated areas were close to the other plots, so it can be assumed that pretreatment populations of soilborne organisms were within the range of those shown for the other plot areas. Further, Metam-sodium was not applied in the prescribed manner. A prescribed rate of material was all applied during a 15 minute period, and was followed by approximately 1 hours irrigation.

The first post-treatment sampling for Fusarium showed lowest populations in the Telone plots, followed by Metam-sodium, MC-33, Dazomet 300, Dazomet 150, and untreated check. However, by March 1986, lowest populations were in the MC-33 plots followed by Dazomet 300, Dazomet 150, Metam-sodium, Telone, and untreated check. Both Telone and Metam-sodium applied in this manner theoretically should not have had significant affect on Fusarium populations. This eventually proved to be true by the March sampling. The unexpected initial drop in populations is unexplained.

MC-33 gave the best overall control. There was little difference between the two rates of Dazomet by spring of 1986. Similar trends occurred with Pythium populations.

At this test site there were five plant parasitic genera of nematodes present. Only the Root-lesion nematode (Pratylenchus penetrans) is of importance to conifers, and so is the only one reported on here (Table 11). MC-33 gave best control, followed by Dazomet 300, Dazomet 150, Telone, Metam-sodium, and untreated check.

Nursery C

At this nursery Dazomet at 200 and 350 ppa were compared with Vorlex for control of soilborne fungi. Pretreatment samples were collected by nursery personnel, and therefore only one composite was collected for the Dazomet and check plots, and one composite for the Vorlex plot which was applied operationally to another portion of the block. The Vorlex treated area had almost 9 times the level of Fusarium, as did the Dazomet treated areas. This should be kept in mind in evaluating the results in Table 12.

Both rates of Dazomet and the Vorlex treatment all reduced populations by approximately the same percentage (97-99%), at the first post treatment sampling. By sowing time populations under all chemical treatments had reached approximately the same level. This was approximately 1/2 that of the untreated plots.

Both Dazomet treatments reduced Pythium populations to 0 at the first post treatment sampling, and they remainded at that level until sowing. The Vorlex treatment reduced populations to below 10 ppg of soil and this too remainded at that level until sowing.

There was no significant difference in seedling stand or mortality amongst the plots. Again, populations at sowing were below threshold levels, which would probably explain this situation.

SUMMARY AND CONCLUSIONS

Efficacy

All the soil fumigants tested, (MC-33, Vorlex, Dazomet, and Metam-sodium), at appropriate rates gave equal control of soilborne microorganisms. Vorlex is somewhat less effective in weed control.

Ease of Application

Each fumigant has its own advantages and disadvantages. MC-33 requires very specialized equipment both for injecting the material into the soil and for immediate tarping. Further, tarp removal and disposal must be considered. However, because it is injected as a gas, treatment time is very short and is less prone to subsequent phytotoxicity problems, although seedling stunting has been associated but not demonstrated to be related.

TABLE 6.--EFFECT OF SOIL FUMIGATION TREATMENTS ON SOIL POPULATIONS OF FUSARIUM - NURSERY A

TREATMENT	FUSARIUM/SAMPLE DATE 9-13-85	10-29-85	3-19-86	6-2-86
0	1198	1043	410	837
MC-33	1698	7	10	53
VORLEX	722	97	63	80
BG 150ppa	1303	813	360	543
BG 300ppa	1547	400	203	213

Values are an average of 3 replications and reported as propagules/gram of soil. Sampling date 9-13-85 is pretreatment, remainder are post-treat.
Treatments: 0 = no treatment; MC-33 = Methyl bromide-chloropicrin @ 350 #/ac (ppa); Vorlex = @ 100 gal/ac; BG = Basamid-Granular @ 150 & 300 ppa.

TABLE 7.--EFFECT OF SOIL FUMIGATION TREATMENTS ON SOIL POPULATIONS OF PYTHIUM - NURSERY A

TREATMENT	PYTHIUM/SAMPLE DATE 9-13-85	10-29-85	3-19-86	6-2-86
0	91	70	154	113
MC-33	84	0	0	0
VORLEX	60	0	0	13
BG 150ppa	89	90	0	23
BG 300ppa	97	47	17	22

(See notes Table 6).

TABLE 8.--EFFECT OF BASAMID-GRANULAR ON SOIL POPULATIONS OF PYTHIUM AND FUSARIUM - NURSERY B

	PYTHIUM & FUSARIUM/SAMPLE DATE					
	10-17-85		10-29-85		3-19-86	
TREATMENT	PY	FU	PY	FU	PY	FU
0	122	1677	108	525	3	205
250 ppa	140	3703	35	160	90	420
300 ppa	147	1528	5	50	10	180

Values are an average of 4 replications and reported as propagules/gram of soil. Sampling date 10-17-85 was pretreat, remainder post treat.

TABLE 9.--EFFECT OF SOIL FUMIGATION TREATMENTS ON SOIL POPULATIONS OF FUSARIUM - NURSERY C

	FUSARIUM/SAMPLE DATE		
TREATMENT	10-2-85	10-29-85	3-19-86
0	1402	1575	453
MC-33	1297	123	65
TELONE	-	58	430
SP	-	120	238
BG 150	1120	980	168
BG 300	1370	720	155

Values are an average of 4 reps and reported as propagules/gram of soil. Sampling date 10-2-85 was pretreat, remainder post-treat.
Treatments: 0 = untreated; MC-33 @ 325 #/ac; Telone II @ 30 gpa; SP = Soil-Prep @ 100 gal/ac; BG = Basamid-Granular @ 150 & 300 #/ac; - = no sample taken.

TABLE 10.--EFFECT OF SOIL FUMIGATION TREATMENTS ON SOIL POPULATIONS OF PYTHIUM - NURSERY C

	PYTHIUM/SAMPLE DATE		
TREATMENT	10-2-85	10-29-85	3-19-86
0	125	77	183
MC-33	121	3	3
TELONE	-	40	123
SP	-	20	65
BG 150	126	30	60
BG 300	113	13	35

(See notes Table 9).

TABLE 11.--EFFECT OF SOIL FUMIGATION TREATMENTS ON ROOT LESION NEMATODES - NURSERY C

	NEMATODE/SAMPLE DATE		
TREATMENT	10-2-85	10-29-85	3-19-86
0	294	463	200
MC-33	387	1	33
TELONE	-	69	88
SP	-	257	100
BG 150	513	156	44
BG 300	356	1	0

Values are an average of 4 replications and reported as number/pint of soil.
(also see notes Table 9).

TABLE 12.--EFFECT OF SOIL FUMIGATION TREATMENTS ON SOIL POPULATIONS OF FUSARIUM & PYTHIUM - NURSERY D

	FUSARIUM & PYTHIUM/SAMPLE DATE							
	10-14-85		11-8-85		3-19-86		6-3-86	
TREATMENT	FU	PY	FU	PY	FU	PY	FU	PY
0	656	97	393	149	333	3	497	63
BG 200	656	97	3	0	40	0	265	0
BG 350	656	97	13	0	3	0	203	0
Vorlex	5827	142	210	7	-	-	148	8

Values are an average of 3 reps and reported as propagules/gram soil
Sample date 10-14-85 is pretreat, remainder are post-treat.
Treatments: 0 = untreated; BG = 200 & 350 #/ac; Vorlex = 35 gal/ac.
- = no sample taken.

Vorlex also requires special soil injecting equipment, but does not require tarping. Treatment time and evacuation from the soil is somewhat longer than MC-33, but about equal to Dazomet and Metam-sodium.

Metam-sodium requires large quantities of water applied over a long period of time. It further requires a well designed irrigation system with proper sprinkler overlap to get complete coverage. It is also subject to wind displacement of the irrigation water, and volatilization under high temperatures. However, if properly set up, it is actually an easy and inexpensive method of application.

Dazomet is a very find granual and is subject to being wind blown at application if proper equipment is not available. Calibration can also be a problem without proper equipment.

This chemical is actually the easiest to apply as it may only require slight modification of standard nursery equipment. Our tests have shown that bed treatments can be applied in the fall and still remain effective by sowing the following spring.

Safety

MC-33 and Vorlex are the most dangerous chemicals of those tested. They both carry a danger-poison label, and are restricted use pesticides. Special protective gear is required during application of these chemicals.

Dazomet and Metam-sodium carry only warning labels, and are much safer to handle. Less specialized safety equipment is necessary during the application of these chemicals.

Cost

Treatment costs depend a lot upon whether or not a nursery owns the specialized pieces of equipment needed to apply the chemicals. Treatment with MC-33 is probably the most expensive, followed by Metam-sodium, Dazomet, and Vorlex. These costs will vary somewhat according to rate used and whether total area or bed treatments are employed.

The selection of a soil fumigant will depend upon the soilborne problems within a nursery. Once the problems have been clearly defined, selection of a fumigant can be based on the above criteria, i.e. ease of application, efficacy, safety, and cost. All of this should be done in light of the processes outlined in my previous presentation on "Options in Controlling Soilborne Pests".

Fumigation Effect on Soilborne Pathogens, Mycorrhizae, and Growth of Douglas-fir Seedlings[1]

Yasuomi Tanaka[2], K.W. Russell[3] and R.G. Linderman[4]

Abstract.--Soils were treated with methyl bromide/ chloropicrin (MBC) at 360 lbs/A and 720 lbs/A or with Basamid at 350 lbs/A in a field trial with a randomized block design at two bare-root Douglas-fir nurseries near Olympia, Washington in 1984-85. The results showed that fumigation (1) increased fall 1+0 seedling count, (2) caused no 1+0 stunting or growth loss, (3) did not hinder formation of mycorrhizae, (4) suppressed and maintained low soilborne pathogen populations and (5) suppressed root infections by Fusarium spp. but not Pythium spp.

INTRODUCTION

The stunting of 1+0 Douglas-fir seedlings is frequently observed in the bare-root nurseries in the Pacific Northwest. It is characterized by a short stem (usually less than three inches long), short needles and a well defined terminal bud resulting from an early cessation of seedling growth. The distribution of stunted seedlings is random often occurring in patches. To determine the cause of stunting we conducted a number of studies the past several years. Although the stunt syndrome is not fully understood it appears that first-year Douglas-fir seedlings develop these symptoms under various stressful conditions. Based on our observations and those of other researchers, a number of factors appear to contribute to stunting, both singularly and more possibly in combination. They include an insufficient level of soil nutrients -- mainly phosphorus and to some extent nitrogen, an excessively high pH resulting from liming, a short growing season resulting from late sowing, an excessive buildup of soil pathogens or undesirable substances in the soil, and a deficiency or delay of mycorrhization of the root system. The involvement of some of these factors is supported by experimental evidence, while the involvement of others is still hypothetical at this time.

The effect of soil fumigation on mycorrhizal infection and/or microbial recolonization has been investigated in bare-root nurseries (Carpenter and Boyd 1980, Ridge and Theodorou 1972), but its effect on stunting is not well understood. An excessively high rate of application may delay recolonization and thus hinder normal formation of mycorrhizae which may, in turn, contribute to stunting due to decreased capacity for nutrient uptake. On the other hand, an excessive buildup of soilborne pathogens resulting from an insufficient rate or skips of fumigation may result in increased root disease causing stunted trees. To investigate these relationships and as a part of the effort to determine the cause of stunting, we conducted a study on the effect of fumigation on seedling establishment, 1+0 stunting, seedling growth, mycorrhizae development, and incidence of root disease of Douglas-fir as well as changes in population of soilborne pathogens.

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[1] Paper presented at the 1986 Western Forest Nursery Council Meeting held at Vance Tyee Hotel, Tumwater, Washington, August 12-15, 1986.

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For comparison, the study was carried out at two bare-root nurseries near Olympia, Washington; the Mima Nursery of Weyerhaeuser Company and the L.T. Webster Nursery of the Washington State Department of Natural Resources. The results reported here are only for Mima except where mention of the Webster data illustrates important points, but the trends were the same for both nurseries. A full report of data from all treatments at both nurseries is in preparation for publication elsewhere.

MATERIALS AND METHODS

A total of four fumigation treatments were applied at both the Mima and Webster nurseries in a randomized block design with three replications. The fumigation treatments were established in September 1984 as follows:

Treatment 1: Fumigation with methyl bromide/chloropicrin (MBC) (2:1) at 360 lbs/A rate (1x); tarp removed after 1 month.

Treatment 2: Fumigation with MBC at 720 lbs/A rate (2x); tarp removed after 1 month.

Treatment 3: Fumigation with Basamid at 350 lbs/A; no tarp.

Treatment 4: Unfumigated control; no tarp.

MBC was applied in the standard manner by injection at the 6" depth followed immediately by tarping. Basamid granules were applied to the surface then rototilled into the top 6" of soil.

Soil samples were collected from the three replicate plots for each treatment at 1, 2, 4, 6, 8, and 10 months after the September, 1984 fumigation. Three 1" diameter core samples from each plot were separately pooled from two depths, 0-6 inches and 6-12 inches. The core sampler was flamed between plot samples to prevent cross contamination. Combined samples weighing approximately 500 g were screened to eliminate large particles and debris, and refrigerated until soilborne diseases were assayed, usually within one week.

Standard soil dilution plating techniques were employed to determine populations of species of Pythium and Fusarium on selective media for each, namely Rose bengal (Russell 1986a) and Komada's medium (Komada 1975) respectively.

Inoculated Rose bengal plates were incubated in the dark at 20°C for 60-72 hrs, then washed with running tap water to remove the soil particles and thereby facilitate counting. Pythium species were not differentiated, and populations were expressed as propagules/g moist soil.

Fusarium populations were assayed as in the Pythium assays except that the soil was suspended in 0.3% water agar and plates were incubated for 5 days at 22-24°C in natural light and colonies were counted as described by Komada (1975).

Seeds were sown in early May 1985. Seedling emergence counts were made in June based on the number of seedlings present in 6 square feet of bed (1.5 linear feet of bed) determined at 2 locations within a plot. The 1+0 stand counts were made in October. The incidence of 1+0 stunting was also determined within the same 6 square feet areas used for the seedling counts. A seedling was considered stunted if it was less than 3 inches tall from ground to apical bud. Actual stunting incidence was based on linear feet of bed rows within the measured area.

Seedlings used for determination of mycorrhizae colonization were collected from each plot in October 1985 and again in May 1986. A total of 10 seedlings per replicate plot were collected in fall and 15 seedlings in the spring. They were carefully washed to remove adherent soil, bagged and shipped on ice to Corvallis, Oregon where each was examined for presence of mycorrhizae. The percent seedlings with mycorrhizal roots were compared among treatments. Root collar diameter and dry weight of shoots and roots (oven dried at 70°C) were determined for seedlings harvested in October 1985.

The incidence of Pythium and Fusarium root rot was determined on 1-year-old seedlings collected in May, 1986. Root systems were washed thoroughly and cut into approximately 1 cm lengths. Root pieces from 5 seedlings per replicate plot were pooled, surface sterilized with 1.0% sodium hypochlorite for 3 min. and rinsed in sterile distilled water. Twenty-five root pieces from each replicate plot were plated on Pythium or Fusarium selective medium, 5 pieces per plate. Recovery of Pythium was determined after 3-day dark incubation at 20°C; Fusarium plates were incubated in natural light for 10 days at 22-24°C. Recovery was considered positive if one or more colonies emerged from the root piece. The number of positive recoveries became % recovery as an index of root rot incidence.

All data were analyzed using analyses of variance. The treatment differences were tested using the Duncan's new multiple range test at a 5% level of probability (Steel and Torrie 1960). Percentages were analyzed after arcsin transformation.

RESULTS AND DISCUSSION

The results from treatments at the two nurseries were comparable in most regards. No striking treatment effects on seedling emergence were observed. There was, however, a trend toward higher emergence in all fumigation treatments compared to the untreated control and Basamid did significantly increase the emergence by 11% (Fig. 1). The 1+0 seedling count was significantly greater in MBC (1x) and Basamid treatments (by 12%) than in the control. The reduced 1+0 count in the control is probably due to the higher levels of pathogens in soils at the time of sowing as reported below.

The incidence of 1+0 stunting was very low at both nurseries in the blocks used for this study, the highest level being 0.1% at Mima and 2.5% at Webster. The bulk of stunting was found in the control treatments at both nurseries.

In general, fumigation treatments tended to produce larger seedlings and MBC (1x) significantly increased root collar diameter and dry weights of shoots and roots compared to the control (Fig. 2). Root collar diameter and root dry weight were significantly greater in MBC (1x) than in MBC (2x). It is not certain why the higher rate of MBC reduced seedling size. It is possible, however, that beneficial micro-organisms, which were not measured in the study, could have been adversely affected at the 2x rate, which, in turn, contributed to size reduction. An adverse effect (on germination and survival) associated with an increased rate of MBC has been reported for white spruce and several other conifers (Hill 1965).

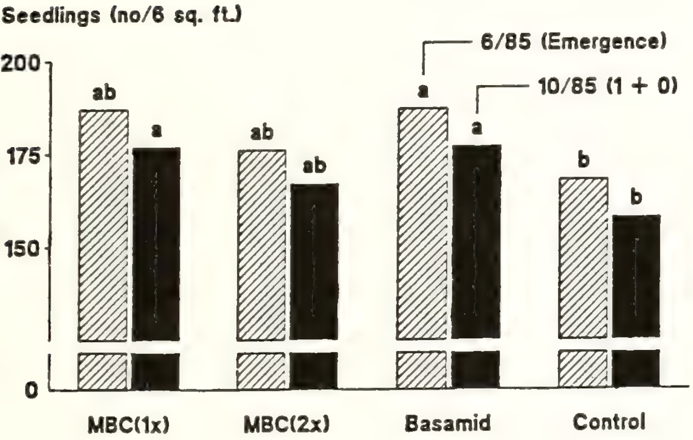

Figure 1.--Effects of soil fumigants on Douglas-fir seedling emergence and 1+0 stand count. The treatments followed by the same letters are not significantly ($p < 0.05$) different within each assessment time.

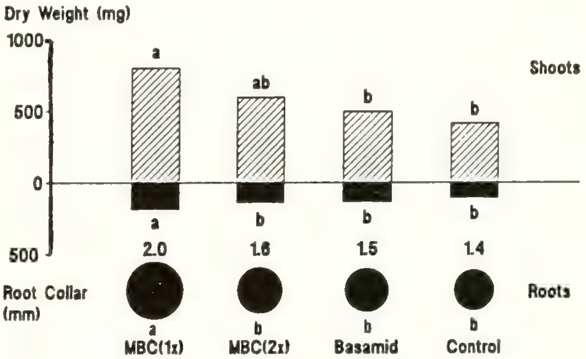

Figure 2.--Effects of soil fumigants on Douglas-fir seedling growth assessed in October 1985. The treatments followed by the same letters are not significantly ($p < 0.05$) different in each variable.

The percent seedlings with mycorrhizae ranged from 60% in the control to 80% in the Basamid treatment in October 1985 (Fig. 3). By May 1986, virtually all seedling roots in the four treatments were mycorrhizal (96%-100%). The differences among treatments were not significant at either assessment time. Contrary to our hypothesis, MBC fumigation up to 720 lbs/A did not hinder mycorrhization of 1+0 Douglas-fir seedlings. Twenty to 40% of seedlings (depending on treatments) had no mycorrhizae, and yet there was virtually no 1+0 stunting in this block at the Mima nursery in 1985. These data suggest that lack of mycorrhization is not the cause of stunting in 1+0 Douglas-fir, although under certain circumstances its presence may prevent stunting.

Fusarium and Pythium populations were assayed at various times after fumigation at the 0-6" and 6-12" depths to determine the efficacy of the fumigation treatments and to determine when these pathogens reinvaded the fumigated treatment plots. The propagule count was usually greater at 0-6" depth than at 6-12" depth (especially with Fusarium), but the trend was the same with respect to seasonal changes and treatment differences. The means of propagule counts for two depths are summarized for Pythium and Fusarium in Figure 4. The data clearly show the effectiveness of MBC fumigation at the normal 1x rate, and that the 2x rate was unnecessary. Basamid was nearly as effective as MBC fumigation in reducing propagule counts.

Pythium populations were effectively reduced by fumigation treatments and remained low throughout the study. In the untreated control, the populations increased in March with the onset of warmer weather, peaked in the May sampling and then declined rapidly by the July sample. Although the magnitude was ten-fold greater, Fusarium population in the unfumigated control fluctuated with a similar trend as those of Pythium. The main difference was that it peaked in March and began to decline thereafter reaching the lowest level in July.

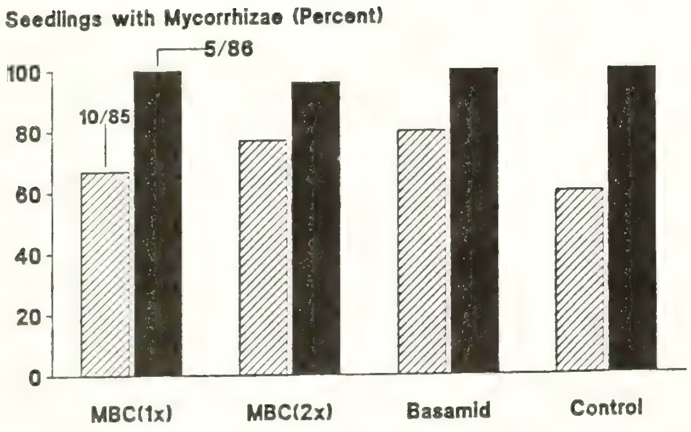

Figure 3.--Effects of soil fumigants on development of mycorrhizae on Douglas-fir seedlings. The treatments followed by the same letters are not significantly ($p < 0.05$) different within each assessment time.

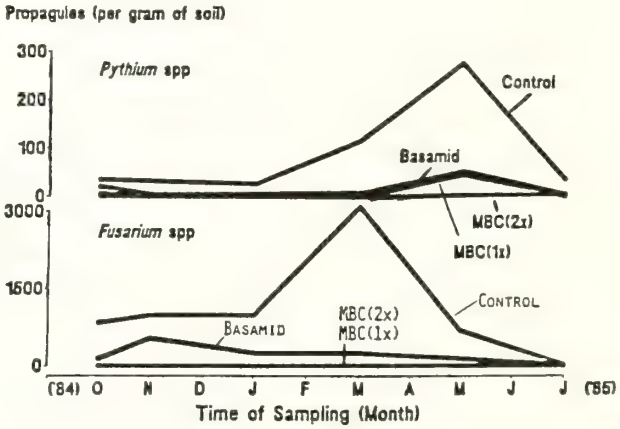

Figure 4.--Effects of soil fumigants on changes in populations of soilborne pathogens.

The reason for the decline in propagule counts of these pathogens in the unfumigated control in mid-summer (July) is not known; however, two possible reasons may be offered: (1) Application of fungicides (Benlate, Captan and Daconil) after sowing possibly reduced the level of fungi, and (2) Dry soil conditions created by the infrequent, deep watering may have contributed to the reduction (Russell 1986b).

The incidence of root rot by Fusarium in May 1986 was highest in the non-fumigated control (Fig. 5). It was not reduced by Basamid as effectively as by MBC at 1x or 2x. Pythium root rot incidence, on the other hand, was nearly as high in all fumigation treatment plots as the non-fumigated control plots in the spring of the second year, presumably due to the aggressive recolonization of fumigated soil from below the fumigation layer. Although pathogenicity of these fungi was not tested in this study, it appeared that species of Pythium involved may not have been as pathogenic as the species of Fusarium based on seedling growth data and 1+0 seedling counts.

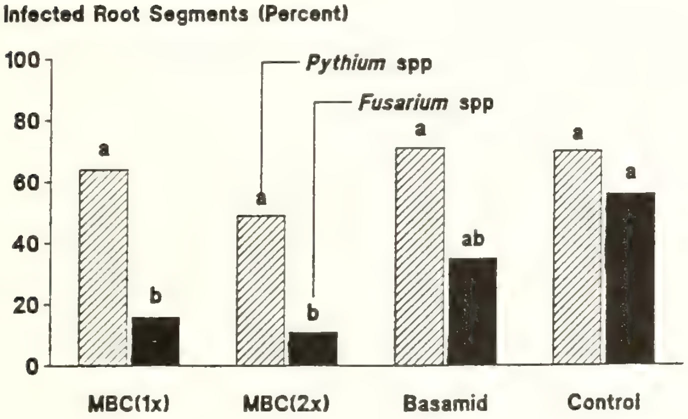

Figure 5.-- Effects of soil fumigants on the incidence of infections of Douglas-fir roots by species of Pythium and Fusarium. The treatments followed by the same letters are not significantly ($p < 0.05$) different in each fungus.

CONCLUSIONS

Based on the results of this fumigation study, the following conclusions were reached.

1. MBC (1x) and Basamid significantly increased 1+0 seedling count by 12% in both treatments.
2. None of the fumigation treatments [MBC (1x), MBC (2x) or Basamid] caused 1+0 stunting or growth loss in root collar diameter and shoot and root dry weights.
3. None of the fumigation treatments caused a reduction in mycorrhizal roots.
4. MBC (1x) and Basamid suppressed and maintained low levels of soilborne pathogens (Fusarium spp. and Pythium spp.) throughout the first full year of seedling growth. MBC at the 2x rate was not necessary for disease control.
5. MBC (1x) and MBC (2x) suppressed root infections by Fusarium spp. but not Pythium spp. in the spring of the second year.

ACKNOWLEDGEMENTS

The authors wish to thank the following people: W. Littke, Weyerhaeuser Co. for his contribution to the disease assay portion of this study, W. Weiland-Alter, USDA/ARS, J. Arthurs and S. Nelson, Department of Natural Resources (DNR) and P. Oster and T. Vu, Weyerhaeuser Co. for their excellent technical assistance, J. Bryan, T. Stevens and J.Hodgin, Weyerhaeuser Mima Nursery and K. Curtis and B. Fangen, DNR L.T. Webster Nursery for their cooperation and support in fumigation treatments and other activities, J.K. Ruthford for preparation of the manuscript, and S. Kaluzny, the Applied Math Department, Weyerhaeuser Co. for her advice in design and statistical analyses. The critical review of the manuscript by W. Littke and T. Stevens, Weyerhaeuser Co., and P. Hamm, Botany and Plant Pathology Department, Oregon State University is greatly appreciated.

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Control and Impact of *Lygus* Damage on 1-0 Douglas-fir Seedlings[1]

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Abstract.--*Lygus* bug feeding on 1-0 Douglas-fir significantly increases cull and the occurrence of forking at harvest. Multiple pesticide applications between July and September can reduce damage by 80-90%.

INTRODUCTION

Since the 1970's, nurserymen in the Willamette Valley have noticed that 2-0 seedlings with multiple tops are associated with deformed terminal growth during the 1-0 year. However, the connection of "bushy-topped" seedlings with the effects of *Lygus* bug feeding is a recent observation (Shrimpton, 1985; South 1986; and Schowalter, et al., 1986). In western Oregon, *Lygus hesperus* Knight is now recognized as a common cause of bud abortion and terminal growth deformation in bare root Douglas-fir (D.f.) seedlings. *Lygus* feeding near the growing tip of 1-0 seedlings results in stem lesions, distorted needles, and deformed tops (Figure 1). Following bud damage, lateral shoots frequently form weak multiple tops (forking) that persist through harvest (Figure 1). Although *Lygus* bugs are a common problem in agricultural crops, they are an unfamiliar pest to most nursery managers.

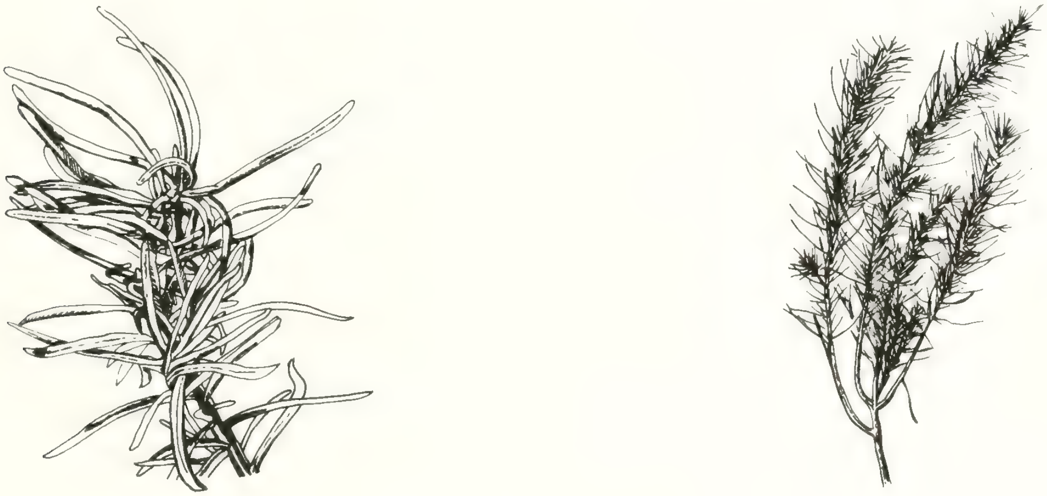

Figure 1.--Appearance of *Lygus* damage in 1-0 D.f. seedling (L) and resulting multiple tops in the 2-0 year (R).

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[1] Paper presented at the Western Forest Nursery Council Meeting, Olympia, WA, August 12-15, 1986.

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Lygus bugs (family Miridae) are sucking insects that feed on the growing tips, buds, and flowers of many plants (Figure 2). Agricultural crops such as alfalfa and cover crops like buckwheat and clover can support high *Lygus* populations. Weed species such as whitetop, tansy, lambsquarter and Queen Anne's lace are also attrative to *Lygus*. During feeding, *Lygus* secrete saliva containing substances that affect the development of plant tissues, often resulting in deformed or aborted growth (Tingey and Pillemer, 1977). Adult *Lygus* overwinter in and around conifer nurseries. During the early spring adults feed and lay eggs in the stems of agricultural crops or herbaceous weeds. The eggs incubate for 10-14 days before hatching into flightless nymphs which, like adults, feed on plant tissue (Kelton, 1975). Three to four generations are completed per year in western Oregon (Berry, 1978). The adult insects are active fliers and readily move from one crop to another. Damage to nursery seedlings starts in July or August and increases gradually through September. During this period, 1-0 D.f. seedlings typically grow 2.5"-4.3" and produce the succulent growth preferred by this insect.

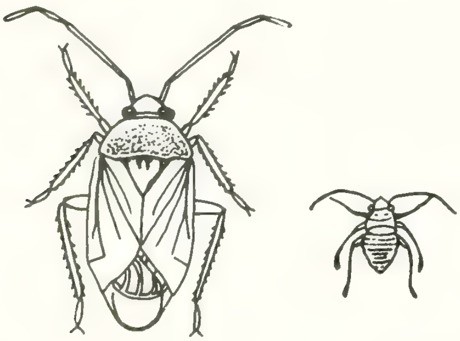

Figure 2.--Adult *Lygus* bug (L) and nymph (R). Adult bugs are 6-7mm long while nymphs vary from 1-6mm in length.

Since 1983, a series of studies on *Lygus* impact and damage prevention have been conducted at bare root nurseries. The objectives of the studies included identifying pesticides effective in reducing damage, timing spray applications, and describing the effects of damage on seedling yields and quality.

MATERIALS AND METHODS

Study Areas

In the summer of 1983 a pesticide screening study was conducted in 1D-0 D.f. (60 seedlings/ft^2) at Weyerhaeuser's Aurora Nursery near Canby, Oregon. Subsequent work on spray timing and the effects of *Lygus* damage on seedling yields were conducted at the D. L. Phipps State Forest Nursery at Elkton, Oregon. Seedling densities at the Phipps nursery varied from 17-25/ft^2.

1983 Pesticide Screening

Insecticides for this study were selected on the basis of registration for nursery crops and use in agriculture for *Lygus* control. 1D-0 seedlings were sprayed weekly between July 21 and September 26. The following insecticides were evaluated:

Insecticide	Rate (Active Ingredient/Acre)
fenvalerate	0.1 lb
acephate	1.0 lb
endosulfan	1.0 lb

The experimental design for the test was a randomized complete block with each block replicated seven times. Treatment plots were 41 ft. x 150 ft. with a 20 ft. buffer separating adjacent treatments. *Lygus* damage was measured in twelve one ft^2 subplots located in the center two beds of each treatment plot.

1983 Impact Assessment

Douglas-fir seedling survival was evaluated in conjunction with the pesticide screening study. Numbers of live seedlings present in a one ft^2 plot located in each treatment replication was recorded in the fall.

1984-85 Pesticide Timing Studies

Based on the gradual damage increase shown in earlier work, it was decided the detection of initial damage among 1-0 seedlings was a suitable marker for timing pesticide applications. In both 1984 and 1985, ten subplots (8 inches x 24 inches) located in four untreated plots were used to monitor seedling damage. The following pesticide regimes were tested using fenvalerate at 0.1 lb active ingredient per acre (A.I./A).

Treatments	Application Timing (weeks from initial damage)
1 (check)	-
2	3
3	2, 5
4	2, 5, 7
5	2, 4, 6, 8, 10, 12

The design for the 1984 study was a randomized complete block with each treatment replicated six times. Treatment plots were 38 ft. wide and over 200 ft. in length. *Lygus* damage was evaluated on the mean of all fifteen 1.5 ft^2 subplots located in the center two beds of each treatment.

During 1984, the effects of *Lygus* damage before and after 20% of the crop had set bud (September 19) was evaluated on 1-0 D.f. The pesticide used to protect seedlings was fenvalerate at 0.1 lb A.I./Acre. This timing study consisted of the following unreplicated treatments installed in four 34 ft. x 150 ft. plots.

Treatment	Protected Period	Pesticide Timing
1 (check)	-	-
2	Aug.-Oct.	Bi-weekly
3	Aug.-Sept.	Bi-weekly
4	Sept.-Oct.	Bi-weekly

The 1985 pesticide study evaluated an operational recommendation of bi-weekly sprays commencing two weeks after *Lygus* damage was first detected. Insecticides chosen for this test were fenvalerate (0.1 lb A.I./A) and acephate at 1 lb A.I./Acre. The design for this test was a randomized complete block with each treatment replicated five times. Treatment plots were 38 ft. wide and over 200 ft. in length. Damage assessment was the same as the replicated 1984 pesticide timing study.

1985 Harvest Assessment

The impact of *Lygus* feeding in the 1-0 year on seedling yields and morphology at harvest was examined using treatment 1 (check) and treatment 5 (6 applications of fenvalerate) from the 1984 pesticide timing study. The three replications evaluated were all located among standard density 2-0 stock (25 seedlings/ft^2). Following undercutting, ten 2 ft^2 seedling samples were removed from the center two beds of the treatment areas. The following data were collected from each sample; live trees/ft^2, % acceptable seedlings, % cull seedlings, and % forked seedlings. Seedlings were classified as cull if their caliper was less than 3mm or height less than 20cm.

Statistical Analysis

Lygus damage was evaluated in the fall of the 1-0 year in the replicated pesticide studies. Seedlings were considered damaged if there were any visible signs of *Lygus* feeding such as distorted needles, stem lesions, deformed buds and forks. Information on tree forking in the unreplicated test was collected during the spring following *Lygus* damage. Seedling forking was evaluated on ten 1.5 ft^2 subplots within each treatment. Seedlings were considered forked if they lacked a dominant terminal shoot. An $\bar{x}$% forking was calculated for each treatment. For the replicated pesticide studies, a $\bar{x}$% of *Lygus* damaged seedlings in each subplot was calculated. Differences between treatments were tested by analysis of variance on arcsine-square-root- transformed percentages. While statistical tests were performed on transformed data, raw data is presented in the tables. Significant differences among several means were tested using Tukey's test (Sokal and Rohlf, 1968). A percentage damage reduction due to pesticide treatments was calculated using the method of Abbott (1925).

RESULTS AND DISCUSSION

Pesticide Tests

Results of the 1983 screening study demonstrated a significant reduction in seedling damage consistent with *Lygus* feeding being the major cause of seedling deformation (Table 1). All of the pesticides evaluated in 1983 provided an acceptable level of control at this high frequency of application.

Table 1.--Percent *Lygus* damage in 1D-0 Douglas-fir seedlings treated with weekly pesticide applications between July 21 - September 26, 1983 at the Aurora Nursery.

Treatment	No. of applications	Seedlings[1] damaged $\bar{X}$(%) 1 plot	Damage reduction (%)
Check	-	14.5 a	-
endosulfan	10	2.4 b	83
acephate	10	2.2 b	85
fenvalerate	10	1.2 b	92

[1] Means not significantly different are followed by the same letter.

When the frequency of application was reduced in 1984, a substantial level of damage reduction was still maintained with as few as two applications of fenvalerate

(Table 2). The 1984 study also indicated that pesticide applications starting two weeks after damage was initially detected provided satisfactory control.

Table 2.--Percent Lygus bug damage to 1-0 Douglas-fir seedlings with different treatment frequencies of fenvalerate (.1 lb A.I./A) at D. L. Phipps Nursery in 1984.

Treatment	No. of applications	Seedlings[1] Damaged $\bar{X}$(%)	Damage reduction (%)
1 (Check)	-	33 c	-
2	1	13 ba	61
3	2	6 ba	82
4	3	6 ba	82
5	6	3 a	91

[1] Means not significantly different are followed by the same letter.

Additional information on pesticide timing resulted from the evaluation of crop protection in relationship to bud set. Seedling protection prior to bud set was critical to reducing the frequency of forked tops (Table 3). Late pesticide application (Sept.-Oct.) did not reduce the frequency of multiple tops.

Table 3.--Effect of pesticide application timing during the 1-0 year (1984) on the occurrence of multiple tops in Douglas-fir seedlings the following spring.

Timing	No. of applications	Forking ($\bar{X}$% ± SE)
Check	-	18.8 ± 2.7
Aug./Oct.	7	4.6 ± 1.5
Aug./Sept.	4	5.9 ± 1.6
Sept./Oct.	3	19.8 ± 2.8

The 1985 pesticide study, showed that four applications, starting two weeks after damage was first detected and continuing on a bi-weekly basis could reduce damage by 80% (Table 4). The timing of the 1985 spray regime in relationship to Lygus damage occurring in check plots is shown in Figure 3. Results from all studies show 80-90% damage reduction with 2-10 pesticide applications.

Another approach to timing pesticide applications for Lygus control used by some nursery managers is to monitor for adults and nymphs on weeds in and around seedling beds. If 1-0 D.F. seedlings are of a susceptible size (1-1.5" in height) and Lygus is detected on weed species, pesticide treatments are initiated. With this system of spray timing, applications will start earlier than in our studies.

Table 4.--Percent Lygus bug damage in 1-0 Douglas-fir seedlings treated with pesticide at two week intervals between July 17 and September 6, 1985 at the D. L. Phipps Nursery.

Treatment	No. of applications	Seedlings[1] damaged $\bar{X}$(%) 1 plot	Damage reduction (%)
Check	-	61.9 a	-
acephate	4	10.0 b	84
fenvalerate	4	10.6 b	83

[1] Means not significantly different are followed by the same letter.

Since relatively low levels of damage can be achieved with 2-4 pesticide applications, it is possible that much of the damage occurring in untreated areas is produced by the flightless nymphs. Lygus nymphs are easily eliminated with pesticide applications. However, the highly mobile adult Lygus enter and leave nursery beds throughout the summer and are a difficult target for foliar sprays. Spraying in the early morning, when adult Lygus are sluggish, may increase the effectiveness of contact insecticides. Factors rapidly reducing pesticide efficacy on Lygus include heavy irrigation of 1-0 crops and the rapid growth of seedlings.

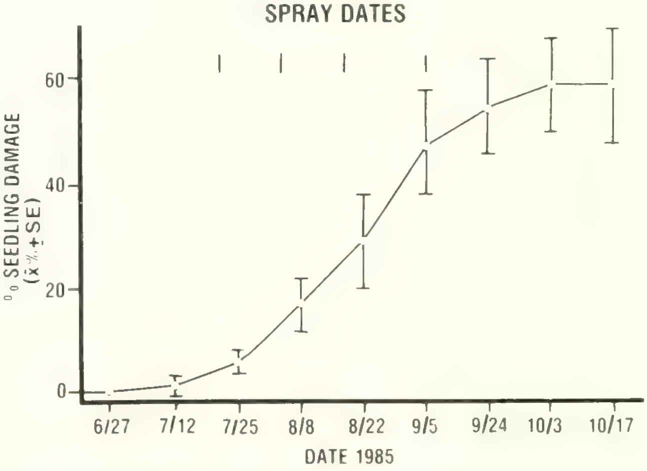

Figure 3.--Mean percent Lygus damage in 1-0 Douglas-fir check plots at the D. L. Phipps nursery in relationship to the 1985 spray schedule.

Lygus Impact

An unexpected result of the 1983 insecticide test was a significant increase in seedling survival in treated plots (Table 5). Increased seedling survival paralleled the trend in damage reduction. A possible explanation for this phenomena might be increased competition and disease in untreated beds. One effect of *Lygus* damage is increased production of lateral shoots which result in greater shading in high density seedling beds and produce conditions favorable for the foliage disease *Botrytis*.

Table 5.--Average fall 1-DO seedling density in beds treated with insecticide for control of *Lygus* damage at the Aurora Nursery in 1983.

Treatment	$\bar{X}$(%)[1] seedlings/ ft2	Increased survival (%)
Check	53.4 a	-
endosulfan	61.4 b	15
acephate	61.7 b	16
fenvalerate	62.3 b	17

[1] Means not significantly different are followed by the same letter.

The 1985 harvest study showed a significant decrease in cull associated with treated seedlings (Table 6). Many seedlings classified as cull had clear evidence of *Lygus* damage in the 1-0 year. Reduction of *Lygus* damage also produced a significant reduction in forked tops. There was no significant difference in the average number of surviving seedlings associated with treatment. *Lygus* damage occurring in the 2-0 year was not significant enough by itself to produce cull. However, seedlings stunted by *Lygus* damage in the 1-0 year and attacked again as 2-0 seedlings were sometimes culled for size.

Table 6.--Harvest evaluation of 2-0 Douglas-fir protected from *Lygus* damage in the 1-0 year (1984) at the D. L. Phipps Nursery.

		$\bar{X}$%[1]		
	$\bar{X}$ Trees/ft^2	Acceptable	Cull	Forked
Check	25.8 a	81.2 b	18.8 b	29.1 b
Treated	29.4 a	89.0 a	11.1 a	6.1 a

[1] Means not significantly different are followed by the same letter.

Conclusions

Lygus damage to 1-0 Douglas-fir seedlings can result in significant increases in cull for caliper and size at harvest. Seedlings not protected from *Lygus* feeding have a higher percentage of multiple tops. *Lygus* feeding on 1-0 seedlings prior to the start of bud set is the greatest contributor to multiple tops. At the D. L. Phipps State Forest nursery, pesticide applications start within 2 weeks of initial damage to the 1-0 crop and are repeated at bi-weekly intervals through August. This procedure has reduced *Lygus* damage to seedlings by 80-90%.

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Meeting Notes

MINUTES FROM THE BUSINESS MEETING

A short meeting was held during the noon lunch on Thursday, August 14.

The main topic was to discuss the location of the meeting in 1988.

Ralph Huber, B.C. Forest Service advised us they would host the meeting at Vernon B.C.

It was also noted that the meeting for 1990 may be hosted by the Phipps Nursery at Elkton, Oregon, however, a representative from Phipps was not available for confirmation.

MESSAGE FROM CHAIRPERSONS

Beautiful Northwest weather, excellent speakers and great field trips made this conference very informative and enjoyable.

Our thanks go to all of the speakers,and to everyone of the 187 attendees registered, for helping make this an outstanding meeting.

It is our hope that everyone gained a lot of useful information from excellent presentations by the speakers, and also retain outstanding memories of the field trips highlighted by blocked roads, or seeing the large herd of elk on the final days visit to Mt. St. Helens.

We wish to thank the nursery staffs at the I.F.A. Inc. Toledo Nursery, the Weyerhaeuser Mima Nursery, and the Dept. of Natural Resources Webster Forest Nursery, for the help and support they gave to make this meeting a success.

We look forward to seeing all of you again in 1988.

Jim Bryan
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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526

United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
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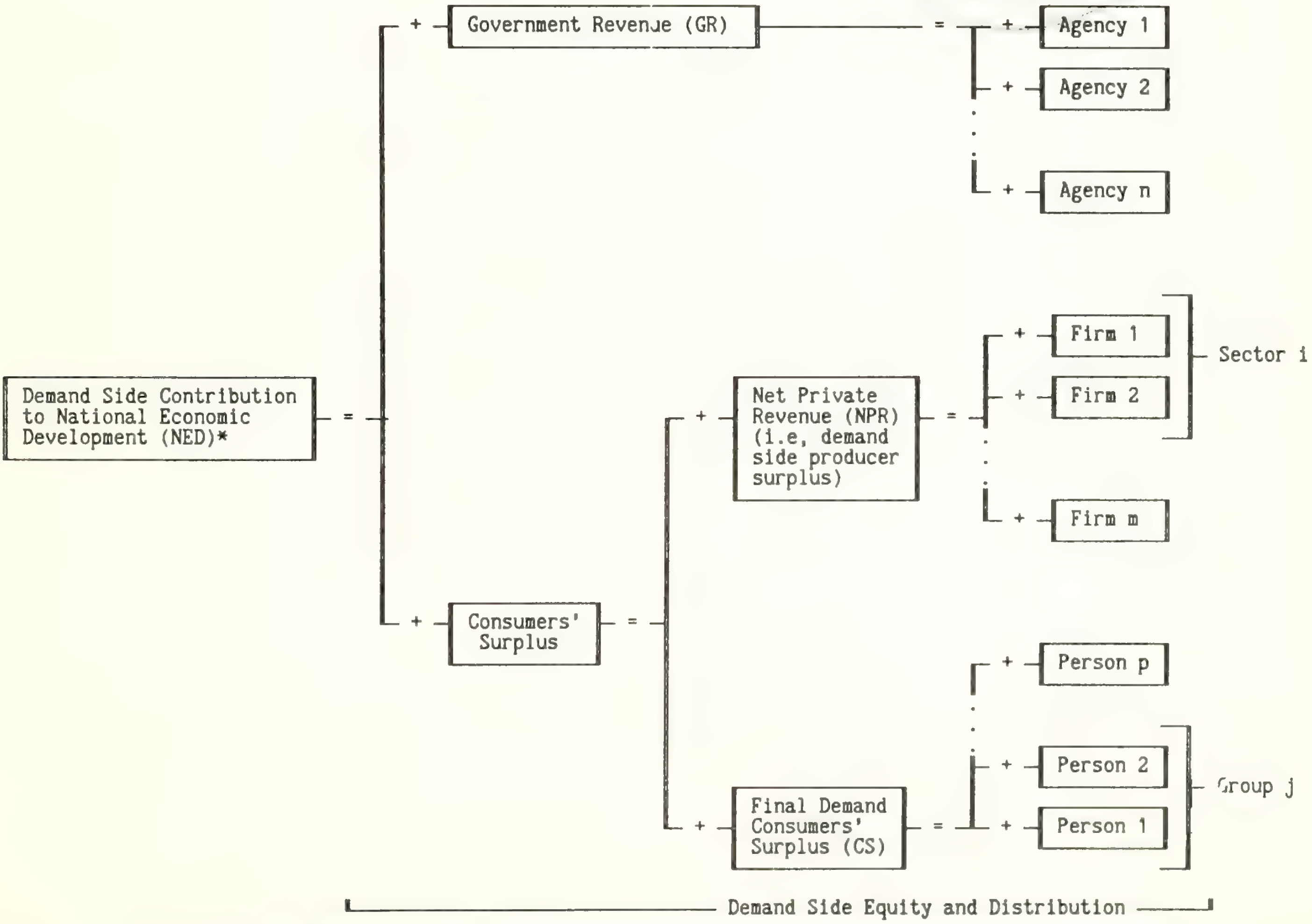
**General Technical
Report RM-138**

An Improved Framework for Estimating RPA Values

**George L. Peterson, Thomas C. Brown,
and Donald H. Rosenthal**


Demand Side Contribution to National Economic Development (NED)*
=
+
Government Revenue (GR)
=
+
Agency 1
+
Agency 2
+
Agency n
+
Consumers' Surplus
=
+
Net Private Revenue (NPR) (i.e, demand side producer surplus)
=
+
Firm 1
+
Firm 2
+
Firm m
Sector i
+
Final Demand Consumers' Surplus (CS)
=
+
Person p
+
Person 2
+
Person 1
Group j
Demand Side Equity and Distribution

* For net contribution to NED, supply costs (including external costs) must be subtracted.

USDA Forest Service
General Technical Report RM-138

January 1987

An Improved Framework for Estimating RPA Values

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Abstract

An RPA value is defined in terms of the philosophical basis for valuation, the objectives and accounts to be served, alternative planning models and pricing policies, the reference for change, and the assumed efficiency of past and future decisions. Guidelines for estimating and reporting RPA values are provided.

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An Improved Framework for Estimating RPA Values

George L. Peterson, Thomas C. Brown, and Donald H. Rosenthal

RPA Values and Properties

The Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974, as amended by the National Forest Management Act of 1976 (NFMA), was passed to make natural resource planning more rational and accountable. The RPA calls for planning at two levels, the national level and the forest level.

Two key documents produced at the national level are the Assessment and the Program. The Assessment describes the forest and rangeland situation at present, and analyzes the environmental, social, and economic trends that will likely affect the resource situation over the next 50 years. Opportunities and obstacles to make changes in the current and future resource situations are described for both public and private lands. Based on the findings of the Assessment, the Secretary of Agriculture recommends to the Congress a 50-year RPA Program for the Forest Service. The Recommended Program is a strategic plan that establishes long-term resource management goals. In the planning process, alternative national plans are developed that each reflect a different emphasis on the various resource management goals—a different strategy for meeting societal needs over the next 50 years. Each alternative includes elements for the three branches of the Forest Service—the National Forest System, Research, and State and Private Forestry. Each plan consists of many intermediate objectives that measure performance in attaining the goals.

In choosing which plan to recommend, the Secretary of Agriculture considers the environmental, social and economic consequences of each alternative. To analyze the economic consequences of each plan, it is helpful that the differing levels and timing of resource outputs are reduced to a common denominator and point in time. Dollars have been selected as the denominator and the present time as the point of comparison. Demand-side unit values must be estimated for each resource output or category of outputs to compute the value of benefits generated by each alternative plan. These unit values have been referred to as "RPA values." When supply costs are subtracted from the demand-side value of total resource outputs in any single year, the remainder is net value. Discounting net value to the present yields present net value (PNV). Present net value is used to rank alternatives in decreasing order of economic value. The PNV by resource output and the overall ranking are important decision criteria.

RPA values are also used in the forest planning process established under NFMA. Again, the values are used to analyze economic consequences of differences in resource output and to rank alternatives.

Several obstacles have prevented effective estimation and application of RPA values. Some resource outputs are exchanged in competitive markets and some are not. The forest management activities to be evaluated cause only marginal changes in output levels for some forest products and nonmarginal changes in others. Demand for some forest products is derived from demand for goods manufactured from the forest products, while other products are objects of final demand. If consistent, comparable values are to be developed for each resource output, these differences in products and the demands they create require analysts to use different methods to estimate values or to apply the methods in different ways. Proper application of methods and the values they produce requires clear understanding of complex concepts and clear separation of technical and policy issues. This report examines these problems and offers an improved framework for defining and estimating demand-side forest product values.

To be correct from the point of view of economic efficiency, an RPA value should be the demand-side per-unit monetary value for a specific change in the quantity of a forest product supplied at the on-forest point of production, i.e., the residual bid, or willingness to pay (WTP) per unit, to the Forest Service (or other land management agency) for the change. If the change in quantity does not cause a significant price change, it is marginal. Then, if the market is in efficient equilibrium, the current price is the appropriate RPA value, and the value of the entire marginal change is simply price multiplied by quantity. If the supply change causes a significant change in price, it is non-marginal. Then, the individual units comprising the change in output each will be valued differently. The value of the entire change is calculated by integrating the on-forest demand function over the range of the price change. An average unit price can be calculated for the change as a descriptive index and used as an RPA value. It applies only to that specific change and cannot be generalized to larger or smaller changes that yield a different average price.

Whether a change is marginal or non-marginal, its value may or may not be fully captured by the responsible land management agency. WTP for marginal change usually is fully capturable as revenue to the supplier under a uniform pricing policy. However, as with underpriced range permits, policy may dictate otherwise. When quantity is rationed by means other than price, the supplier is not likely to capture all the value.

WTP for nonmarginal change in output generally is not fully captured as revenue to the supplier under uniform pricing. When full WTP is not captured, there will be surplus to purchasers of the forest product. When the surplus is captured by firms that use the product as input in the production of income, the surplus is demand side producers' surplus (PS), income retained as real profit. When the surplus accrues to consumers who use the product in final demand, it is consumers' surplus (CS); that is, the surplus is income retained by the consumer as real purchasing power.

The value of an on-forest product can vary by production location if there are differences in access to markets and, hence, differences in shipment costs, or if there are differences in local site attributes that cause production and extraction costs to vary from place-to-place. Therefore, it would not be reasonable to expect a single RPA value to be valid region-wide for a given forest product. However, it may be possible to estimate region-wide prices or demand models for derived products such that location-specific RPA values for the on-forest product can be derived with little expense or complication. For example, a site specific stumpage value could be derived from a regional lumber demand model.

The Philosophical Basis for Valuation

Figure 1 shows that value can be defined by individual preferences (consumer sovereignty), by government authority as in a command economy, or by other criteria. Consumer sovereignty is the basis for competitive markets and neoclassical microeconomic theory. It is also the constitutional platform from which government is derived by social contract in the United States.

Given consumer sovereignty as the justification for value, it is then necessary to agree on a basis for assigning and measuring value. One approach is to accept the "exchange value" concept of neoclassical economic theory. Under this approach, a thing is worth the amount of money for which it can or could be exchanged, which is determined in a competitive market by equilibration of willingness to pay (WTP) and compensation demanded (CD). It is reasonable and consistent to adopt this competitive market model for assigning RPA values.

However, actual values are reflected by the sovereign preferences of people as expressed through due process. Values derived solely from economic theory may not reflect political reality. Other bases for assigning value are conceivable, such as voting behavior or various nonmonetary valuation methods. It is also important to recognize that monetary exchange values depend on the existing distribution of income. The results might be different under some other income distribution.

Given the economic definition of value in exchange as derived from individual preferences and competitive market transactions, it is necessary to identify ways to measure WTP and CD. There are two basic approaches: (1) observation of demand in real markets, and (2) observation of demand in hypothetical markets. Observation of demand for private goods traded in real markets yields prices (i.e., demand at the point of intersection with supply) that can be used to value marginal changes. However, it is necessary to evaluate all observed prices for distortion. Where market imperfections exist, observed prices may not be valid.

When quantity changes are not marginal, it may be necessary to estimate a portion of the demand function from observation of market transactions in order to

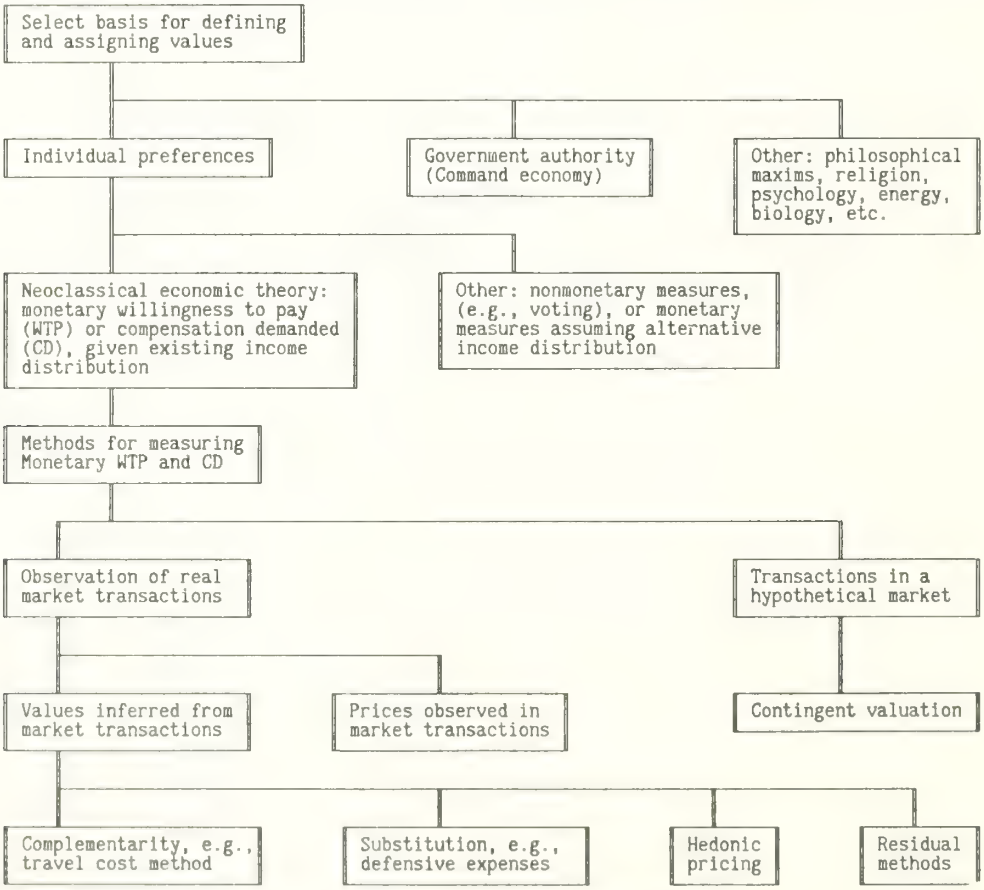

Select basis for defining and assigning values
Individual preferences
Government authority (Command economy)
Other: philosophical maxims, religion, psychology, energy, biology, etc.
Neoclassical economic theory: monetary willingness to pay (WTP) or compensation demanded (CD), given existing income distribution
Other: nonmonetary measures, (e.g., voting), or monetary measures assuming alternative income distribution
Methods for measuring Monetary WTP and CD
Observation of real market transactions
Transactions in a hypothetical market
Values inferred from market transactions
Prices observed in market transactions
Contingent valuation
Complementarity, e.g., travel cost method
Substitution, e.g., defensive expenses
Hedonic pricing
Residual methods

Figure 1.—How is value defined and measured.

assign value to the changes. Goods not traded in real markets sometimes can be priced by derivation from the prices of market goods through complementary or substitute relationships. Travel cost analysis and hedonic pricing are examples.

The hypothetical market methods are generally termed "contingent valuation methods" (CVM). Demand (i.e., marginal willingness to pay as a function of quantity purchased) is estimated by observing the choices and exchanges people make in hypothetical (i.e., experimental) market situations.

Market imperfection generally involves "non-market" goods that are somewhat non-excludable or non-rival in consumption. Production of such goods usually is not profitable to private enterprise, even though failure to produce may be inefficient from a societal viewpoint. If economic efficiency is of concern, the value of public as well as private goods must be estimated.

Objectives and Accounts Served

"Value" also depends on the objectives to be served by the evaluation in which an RPA value is used. Economists often assume the objective is economic efficiency. This follows from their acceptance of consumer sovereignty and market mechanisms for allocating resources. Economic efficiency can be applied over any desired geographical or political boundary. For Federal agencies, whose boundary is the whole country, the RPA value should measure the demand-side contribution to the national economic development (NED) account (i.e., gross returns to aggregate national economic efficiency). Subtracting the supply costs of an alternative from its demand-side contribution to NED gives the net contribution to NED. The implied question is whether the nation in aggregate is economically better off with or without the proposed change.

However, as shown in figure 2, there may also be other objectives. If an objective is a balanced federal budget, it is important to examine the government net revenue account. Here, value measures the contribution to government revenue (GR), from which government costs are subtracted to estimate contribution to a balanced budget. Other objectives might be concerned about consumers' surplus (CS) or net private revenue (NPR), redistributing income, minimizing government expenditure, and achieving certain levels of output.

A value defined in terms of the NED account can be disaggregated to the GR, CS, and NPR subaccounts. The NED value gives the maximum willingness to pay (or compensation demanded) for the specified change in an on-forest product. If the change is marginal and the product is sold at its competitive market price, the entire NED value of the change is captured by the government agency as GR. Under other circumstances, the consumers of the on-forest product retain some or all of their willingness to pay as consumers' surplus. If the consumers are firms using the on-forest product as an input, the consumers' surplus translates into real profit (NPR) in the

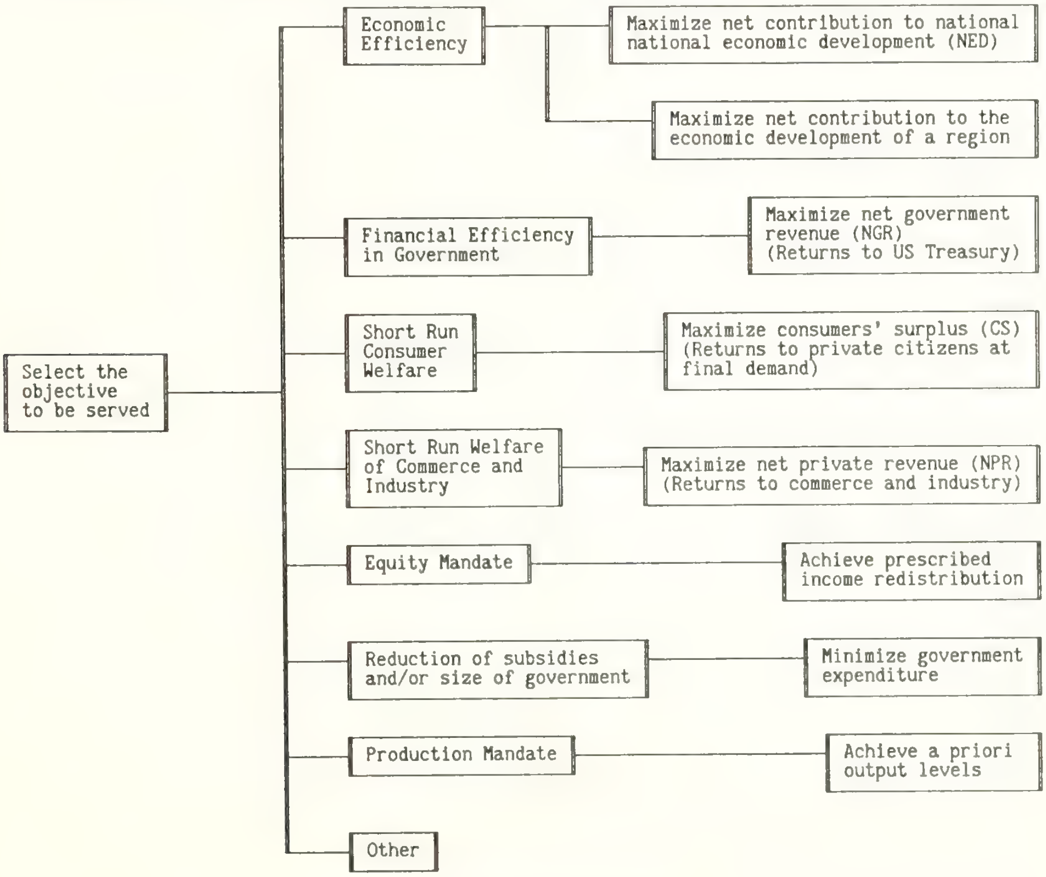

Select the objective to be served
Economic Efficiency
Maximize net contribution to national national economic development (NED)
Maximize net contribution to the economic development of a region
Financial Efficiency in Government
Maximize net government revenue (NGR) (Returns to US Treasury)
Short Run Consumer Welfare
Maximize consumers' surplus (CS) (Returns to private citizens at final demand)
Short Run Welfare of Commerce and Industry
Maximize net private revenue (NPR) (Returns to commerce and industry)
Equity Mandate
Achieve prescribed income redistribution
Reduction of subsidies and/or size of government
Minimize government expenditure
Production Mandate
Achieve a priori output levels
Other

Figure 2.—Possible objectives.

firms' production processes. If the consumers are forest users purchasing for final demand, the surplus remains consumers' surplus (CS). For some changes, two or all three of these accounts receive some value.

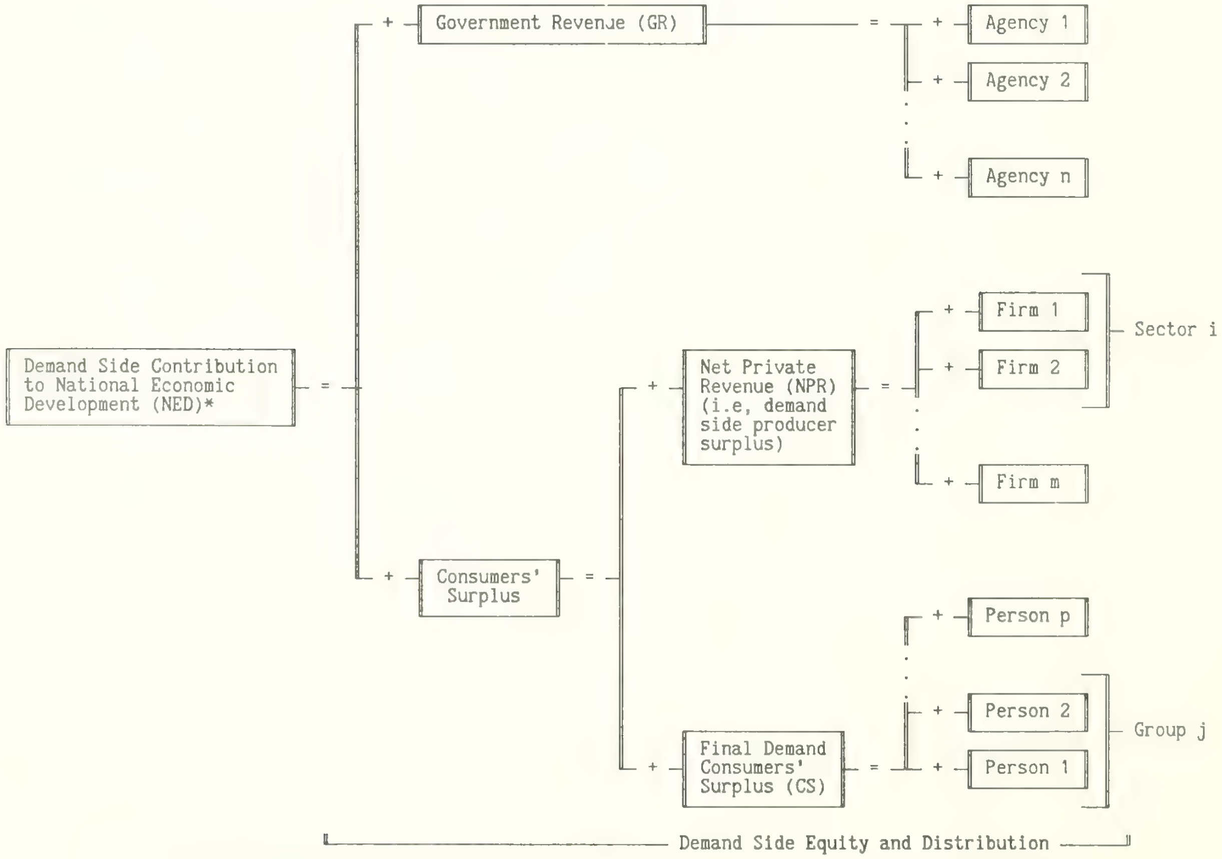
As shown in figure 3, when defined properly, contributions to these three subaccounts sum to the contribution to the NED account. Such disaggregation exposes the distribution of NED gains (or losses) in the three sectors of the economy representing the interests of the U. S. treasury, private citizens, and private industry, and is one way of examining the "equity" of an alternative. Equity is concerned with the distribution of gains and losses among individuals and groups and belongs in the domain of political conflict resolution. Although only three subaccounts have been identified here, many are conceivable (e.g., representing the interests of individuals, geographic regions, ethnic groups, organizations, etc.)

Exposing the impacts of a change in the output quantity of a forest product on various subaccounts is important, because two actions equally efficient and productive from the NED perspective may cause different distribution of impact among the GR, CS, and NPR subaccounts. It is important to examine tradeoffs among these and other subaccounts, because these tradeoffs relate to objectives other than economic efficiency at the aggregate national level. However, to use one of the subaccounts as the sole criterion from which to allocate public resources and thus to estimate RPA values may have bizarre consequences. For example, only looking at the GR account (focusing only on the objective to maximize net government revenue) might lead government to behave as a profit maximizing monopolist. It might also lead to failure to produce valuable non-market goods, such as national defense, education, public utilities, and wilderness. Such outcomes conflict with the economic efficiency objective and the perspective of public trust.

Alternative Planning Models

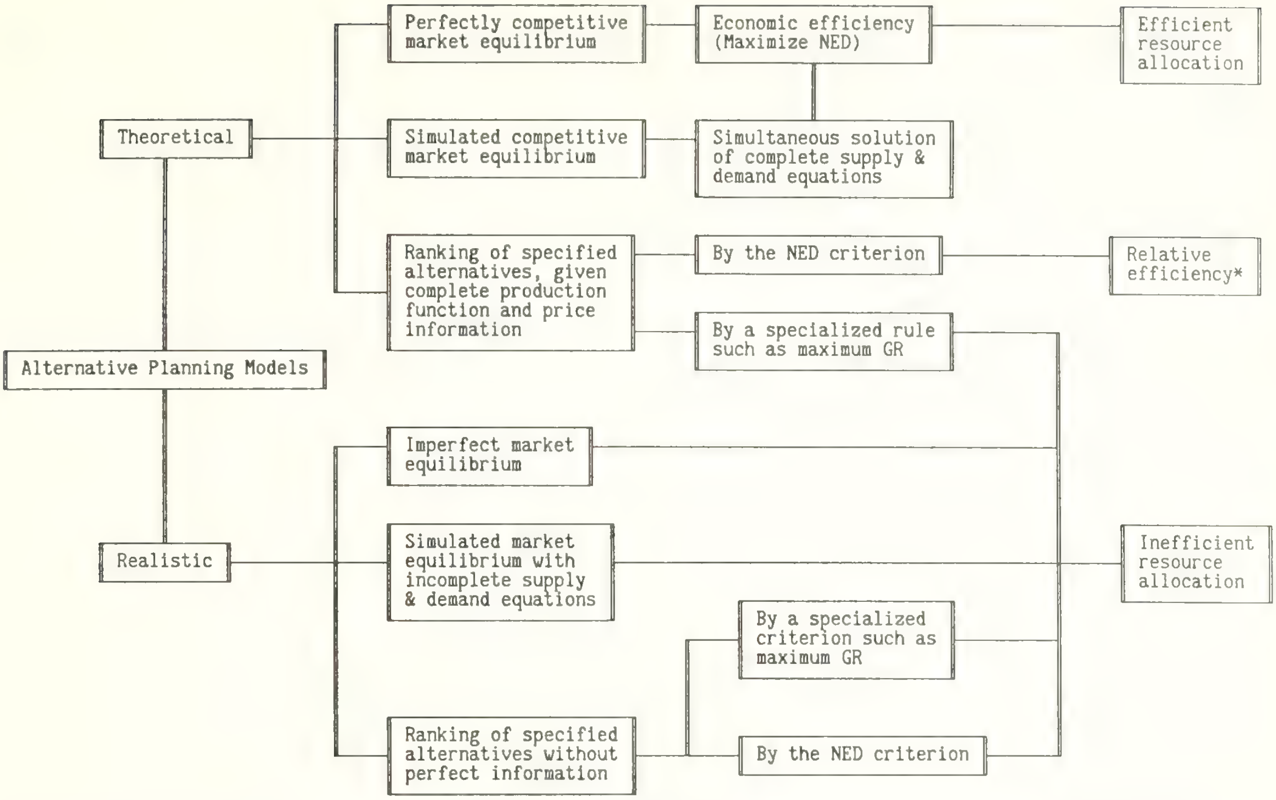
The strategy used in RPA planning is one of trial and error, in which several alternatives are first designed, then evaluated and ranked. To put this approach in proper perspective and to better clarify the purpose of an RPA value, it is useful to look at alternative planning models. Figure 4 presents three basic approaches to resource allocation, which can be further classified either as theoretical or realistic.

The three approaches are: (1) market equilibrium, (2) simulated market equilibrium, and (3) trial and error planning. A market allocates resources and assigns prices by equilibrium between supply and demand (i.e., equation of WTP and CD). In theory, equilibrium in a perfectly competitive market is economically efficient. That is, it would be impossible to make an improvement in the NED account. The resulting resource allocation and prices are


Government Revenue (GR)
Agency 1
Agency 2
Agency n
Firm 1
Firm 2
Firm m
Sector i
Demand Side Contribution to National Economic Development (NED)*
Net Private Revenue (NPR) (i.e, demand side producer surplus)
Consumers' Surplus
Person p
Person 2
Person 1
Group j
Final Demand Consumers' Surplus (CS)
Demand Side Equity and Distribution
+
=

* For net contribution to NED, supply costs (including external costs) must be subtracted.

Figure 3.—Components of the demand side contribution of a government action to national economic development.


Alternative Planning Models
Theoretical
Perfectly competitive market equilibrium
Economic efficiency (Maximize NED)
Efficient resource allocation
Simulated competitive market equilibrium
Simultaneous solution of complete supply & demand equations
Ranking of specified alternatives, given complete production function and price information
By the NED criterion
Relative efficiency*
By a specialized rule such as maximum GR
Realistic
Imperfect market equilibrium
Simulated market equilibrium with incomplete supply & demand equations
Inefficient resource allocation
By a specialized criterion such as maximum GR
Ranking of specified alternatives without perfect information
By the NED criterion

* When alternatives from an incomplete set are ranked by the NED criterion with perfect information, the result is that they are ranked by efficiency, relative to each other. However, the efficient alternative cannot be selected if it is not included in the set. Trial and error modification and ranking of alternatives with perfect information might, but will not necessarily, converge to efficiency.

Figure 4.—Alternative planning models.

the best possible considering the economic efficiency objective and given the initial distribution of income.

However, real markets are imperfect. Monopoly, external diseconomies, and public goods tend to cause equilibrium in real markets to fall short of economic efficiency. Such imperfections are generally regarded as justification for government actions such as RPA planning.

From the economic efficiency point of view, the ideal way to correct market imperfections would be to simulate perfect market equilibrium. In theory, marginal cost (supply) and marginal WTP (demand) equations could be specified for every conceivable product, whether or not such products have the characteristics of private goods. Such equations would include external (social) costs and benefits and joint production and consumption relationships. Simultaneous solution (intersection) of all these supply and demand equations would specify efficient prices and the efficient allocation of resources.

In practice, such an approach is generally not realistic. Complete specification and estimation of all the required equations is not possible at acceptable cost. Simple approximations of some equations might be reasonable; but use of incompletely specified equations for this kind of simulated equilibrium analysis is certain to lead to inefficient allocation of resources.

The third planning approach shown in figure 4 is trial and error. In this approach, designers create a limited set of feasible actions. Presumably, they are guided by criteria that help them create good alternatives. The costs and benefits are estimated and summed for each, for example, as net present worth. When the NED criterion is used, the method is called "benefit-cost analysis" (BCA). Given perfect information about the production functions and prices, BCA ranks the alternatives according to relative economic efficiency. That is, they are ranked in order of their net contribution to NED. If some criterion other than NED (such as GR, NPR, or CS) is used, the alternatives will not necessarily be ranked by relative economic efficiency.

If the NED criterion is used and the set of alternatives evaluated includes the globally efficient one that, in concept, would be the outcome of simulated market equilibrium, it will be ranked first by BCA. However, it is not likely, at least on first try, that the designers will be able to produce this ideal alternative. If they knew how to do that, the trial and error method would not be needed. In theory, iterative redesign and evaluation might converge toward optimal resource allocation; but trial and error planning usually stops short of economic efficiency, even with complete information about production functions and prices.

In practice, such information is also likely to be imperfect. Some of the products will be public goods, and their quantities and prices will have to be estimated by imperfect methods. Therefore, trial and error planning can be expected to produce results that are less than efficient, even when the NED criterion is used. However, it is important to note that when the NED criterion is used, RPA planning aims at the perfect market outcome. Success in achieving that outcome is limited only by information and creativity, not by the direction of aim. When some other criterion (such as GR, NPR, or CS) is used to define the RPA values, the implied aim of the planning process is toward something other than the ideal market (efficient) allocation of resources. Deciding what the aim ought to be is a political responsibility, not a technical responsibility. However, it is important to understand the target.

Alternative Pricing Policies

The prices assumed to be in effect for government supplied forest products will influence returns calculated in the NED, GR, CS, and NPR accounts. Figure 5 shows that pricing policy must be specified as well as the valuation account before estimating RPA values. Use of different assumed pricing policies in ranking RPA alternatives allows pricing policy to be ranked. For example, if the NED account is used, returns to that account from each alternative under each pricing policy might be estimated. The outcome would show which pricing policy gives the greatest return while also ranking the RPA alternatives.

Several hypothetical pricing policies might be considered. From the point of view of neoclassical economic theory, the marginal cost price yields the greatest return to the NED account. This is the price at which marginal cost (MC) and marginal WTP (MWTP) are equal, the condition of equilibrium in the ideal market. However, the MC and MWTP depend on the decision in question. Any cost or benefit that varies with versus without the change is marginal to that decision. A given planning alternative may include both long- and short-run considerations.

Private firms generally strive to maximize profit, which requires MC and marginal revenue (MR) to be equal. Under perfect competition the two rules (MC = MR and MC = MWTP) give the same efficient allocation of resources. When public goods, external diseconomies, or monopolistic conditions are involved, the MC = MR rule gives inefficient results. Use of the GR account by government as the sole criterion for resource allocation is equivalent to the MC = MR rule. Possible consequences include monopolistic behavior, failure to provide public goods and services, and failure to correct external income transfers in the economy.

It is necessary to decide which pricing policy to use as a basis for estimating RPA values. The appropriate pricing policy to use is the one expected to be in place during the planning period of the RPA analysis, unless one of the purposes is to evaluate alternative pricing schemes. Given a decision about pricing policy and accounting stance, figure 5 shows how to proceed with the estimation of RPA values and sub components.

The Reference for Change

Economic value as derived from the rational framework of economic theory and ideal market behavior has meaning only in terms of "with vs. without" the thing to which value is to be assigned. If alternative policy actions are to be ranked, RPA values and the rankings may be different for different null (i.e., "without") alternatives. It is essential to specify the null alternative to which policy alternatives are to be compared before RPA value can be assigned.

The logical null alternative is a continuation of current management direction. It is a practical choice for two reasons. First, the RPA planning exercise is largely an evaluation of whether the current management direction should be changed. Second, existing market prices indicate (except where distortions exist) the value of marginal change from the existing situation, but may not correctly measure the value of marginal change from some other base.

Figure 6 shows five general options for specifying change, where four and five are the practical options.

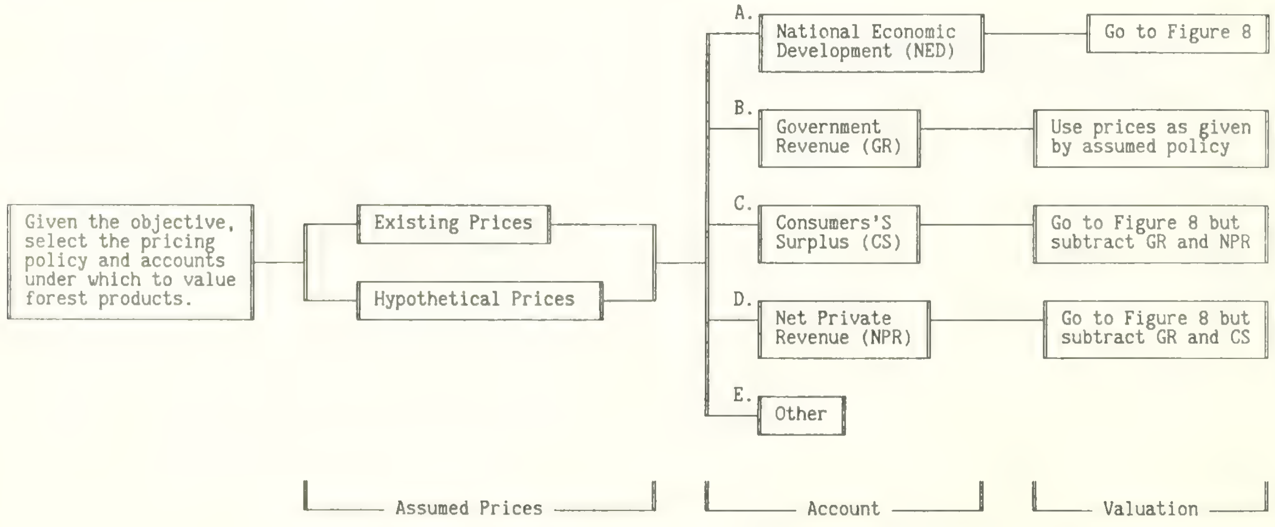

Given the objective, select the pricing policy and accounts under which to value forest products.
Existing Prices
Hypothetical Prices
A.
National Economic Development (NED)
Go to Figure 8
B.
Government Revenue (GR)
Use prices as given by assumed policy
C.
Consumers'S Surplus (CS)
Go to Figure 8 but subtract GR and NPR
D.
Net Private Revenue (NPR)
Go to Figure 8 but subtract GR and CS
E.
Other
Assumed Prices
Account
Valuation

Figure 5.—Alternative pricing policies and accounting stances from which to assign RPA values.

RPA value might be assigned based on the following types of changes from the current situation:

1. no production at all (i.e., zero output),
2. no management at all,
3. custodial management only,
4. realistic alternatives, and
5. one more or one fewer unit.

Values of some on-forest products will differ, depending on which of these types of change is being evaluated. Furthermore, the accuracy with which values can be estimated generally increases from option 1 to option 5 (i.e., as the quantity of change becomes smaller).

The investment unit provides the reference for valuation of a given decision regarding a proposed investment. The investment unit is defined by the level at which the investment decision is being made. With "lumpy" decisions, the investment unit might be a timber sale or recreation site. At a more disaggregate level, the investment unit might be a cord of wood or unit of recreation capacity at an existing site. The RPA value will depend on the unit of investment to which it is to be assigned. For example, the value of a new recreation site divided by the number of its units of recreation capacity is not necessarily the same as the value of one more unit of capacity at the site. This problem is simply another way to state the marginal vs. non-marginal question.

In general, the RPA value should be estimated for the actual changes proposed (i.e, the RPA alternatives that need to be ranked). Such alternatives are generally limited to categories four and five above. The first three are not likely to appear.

Assumptions about the Efficiency of Past and Future Decisions

If past knowledge or control of the future were perfect and if resources were allocated based on neoclassical economic theory, current allocation decisions would be trivial. However, past knowledge and control of the future have been imperfect; therefore, opportunities exist for new investment that are of greater value than some existing operations. Thus, investment and disinvestment decisions may require different RPA values (fig. 7).

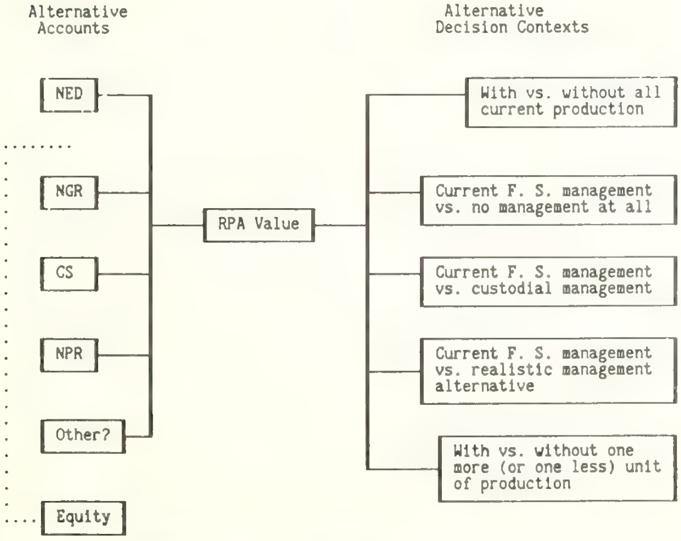

Alternative Accounts
NED
NGR
CS
NPR
Other?
Equity
RPA Value
Alternative Decision Contexts
With vs. without all current production
Current F. S. management vs. no management at all
Current F. S. management vs. custodial management
Current F. S. management vs. realistic management alternative
With vs. without one more (or one less) unit of production

Figure 6.—Interaction of accounting stance with the decision context.

The imperfection of knowledge and control of the future has important implications for the estimation of the RPA values to be used in ranking alternatives, particularly if the alternatives are expressed in terms of allocation of money among Forest Service regions or other management units. If it is not certain how resources thus allocated will be invested, it is not possible to assign an accurate RPA value, because value is conditional on the actual changes proposed. Instead, it is necessary to estimate the most likely value of return on investment in a given management area, given limited knowledge of what that area's investment alternatives are, and how resources will be allocated among them.

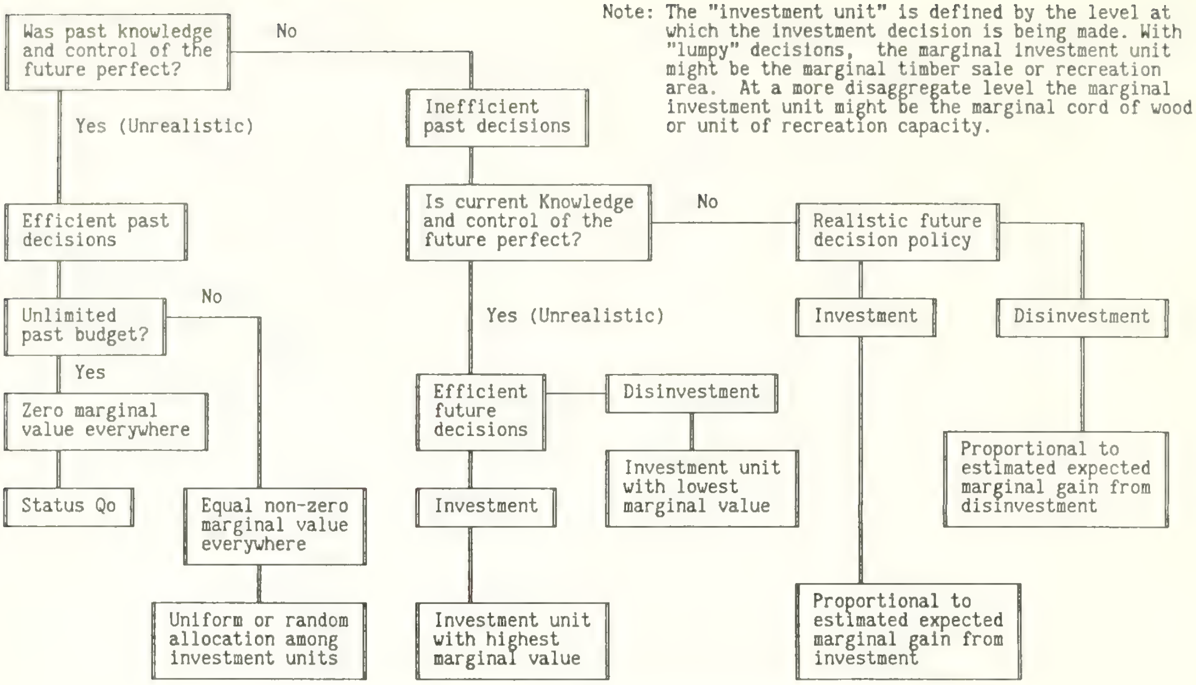
To evaluate and rank all the investment and disinvestment opportunities facing a management area is generally too expensive to be practical. A more reasonable approach is to evaluate a sample of opportunities and then estimate a distribution of value from that sample. For example, assume the management decision is to open new recreation sites or to close existing ones. Value with vs. without each site in a sample of candidate sites could be estimated.

If the investment unit is the recreation site, the proper way to calculate the value of each site is with vs. without that site, assuming all others remain unchanged, i.e., valuation of each site at the margin. If future investments will be random or uniform, the expected value (average) is the best value to use. If the management area will tend to make efficient decisions, the appropriate RPA investment value should be above the average, and the appropriate disinvestment value should be below the average. Exactly how far above or below the estimated average site value these values should be is a judgment call. If high efficiency is expected, the values should be out in the tails of the distribution. If little improvement over randomness is expected, the values should be near the average. It is a matter of the expected productivity of investment decisions in the management area.

Estimation of RPA Values

The recommended procedures for estimating RPA values are highly technical. Many important considerations have been outlined here, but only in the most general terms. It is important not to expect or impose invalid simplifications. Estimation of RPA values requires a combination of (1) explicit performance specifications, and (2) expert command of complex concepts and methods. It is essential to keep policy judgments and technical reasoning separate.

Figures 5 and 8 give a graphic summary of technical guidelines for RPA valuation. These guidelines are outlined in the following sections for various accounts and objectives for which RPA values might be assigned.


Was past knowledge and control of the future perfect?
No
Yes (Unrealistic)
Inefficient past decisions
Efficient past decisions
Is current Knowledge and control of the future perfect?
No
Realistic future decision policy
Unlimited past budget?
No
Yes
Yes (Unrealistic)
Investment
Disinvestment
Zero marginal value everywhere
Efficient future decisions
Disinvestment
Proportional to estimated expected marginal gain from disinvestment
Investment unit with lowest marginal value
Status Qo
Equal non-zero marginal value everywhere
Investment
Uniform or random allocation among investment units
Investment unit with highest marginal value
Proportional to estimated expected marginal gain from investment

Note: The "investment unit" is defined by the level at which the investment decision is being made. With "lumpy" decisions, the marginal investment unit might be the marginal timber sale or recreation area. At a more disaggregate level the marginal investment unit might be the marginal cord of wood or unit of recreation capacity.

Figure 7.—Investment criteria under perfect and imperfect information scenarios.

NED Guidelines and Conclusions

The following statements are based on the conclusion that RPA values are to be defined relative to the National Economic Development account to measure achievement of the economic efficiency objective. Other accounting perspectives, as derived from other objectives such as Government Revenue, Consumers' Surplus, or Net Revenue to Private Firms, are discussed in subsequent sections. Because an RPA value includes only demand-side WTP, these conclusions are not concerned with estimation of supply-side surplus. The conclusions are summarized graphically in figure 8.

1. The question(s) to be answered must be explicitly stated, because economic value has meaning only in terms of change and comparison. In general, the "with vs. without" comparison must be specified before value can be assigned.

2. Forest products and their respective units of supply and demand should be defined by forest product specialists who understand the processes of production and consumption, the application intended for the values, and the valuation process. A major source of confusion in the definition, estimation, and application of RPA values is inadequate or improper definition of units of forest product supply and demand. Units need to be defined in market and policy-consistent terms.

3. Published RPA values should be accompanied by an explanation of how they were derived and a statement of the specific questions to which they are and are not applicable. When values are not accompanied by such information, there is potential for misapplication.

4. Published RPA value information should be accompanied by procedures for estimating forest product values in terms of specific decisions and conditions to which the published "generic" values are not applicable.

5. The demand-side value of a Forest Service action should be defined as net WTP for the change in the supply of on-forest products. "Net" means the residual WTP remaining after payment of all real costs of acquiring the on-forest product other than payments to the Forest Service. "Real costs" refer to the cost of removing or using the forest product, assuming the input factors are purchased at the margin and are priced efficiently.

6. Marginal and nonmarginal change must be carefully distinguished. A marginal change does not significantly change price. A nonmarginal change does. For nonmarginal changes, valuation cannot be achieved in terms of a simple "price times quantity" calculation, unless the "price" is a valid average for the exact change to which value is to be assigned.

7. For a marginal change in the quantity supplied of an on-forest product, the correct demand-side value is the price defined by competitive equilibrium between on-forest supply and demand. That equilibrium occurs at equality between marginal WTP (demand) and marginal cost (supply).

8. The net WTP for marginal changes in the quantity of forest products supplied may not be fully captured by the prices which transfer payment from consumers to suppliers if those prices are distorted (e.g., when consumption is rationed by means other than price and there is excess demand at the existing price).

9. If parallel private competitive markets exist for non-priced on-forest products, the private market prices may be appropriate for valuation of marginal changes in units supplied by the Forest Service. However, because of the possibility of complementarity and substitution between

publicly and privately supplied units of the good, the private market prices should be scrutinized for distortion. Also, adjustment must be made for differences in market structure. For example, with recreation, differences in the relative location of consumers vis-a-vis recreation sites are common, causing price differences that are not easily taken into account. Because of this, private market prices for recreation may have little validity for valuing recreation on public lands. Research is needed to evaluate the effects of substitution relationships, quality differences, population distributions, and site location before comparisons of public and private recreation prices will be meaningful.

10. Where an on-forest product that is not competitively priced can be traced via derived demand to an off-forest private good traded in a perfectly competitive market, the on-forest market equivalent price of a marginal change may be derivable via residual techniques from the price of the off-forest commodity. For example, the marginal value product of an animal unit month of range forage can be estimated from the competitive market for red meat if the competitive prices of other input factors in the production function are known. Before off-forest prices for private goods are used to derive on-forest residual prices, the off-forest prices should be examined for distortion. Where market imperfections are present, the off-forest prices may be incorrect.

11. The off-forest price or demand function should be specified and estimated at the point where the chain of products derived from the on-forest product enters an uninterrupted chain of perfectly competitive markets, or at final demand, whichever comes first. At this point the prices and demand functions will have maximum generalizability, and will be most likely to achieve regionwide applicability. The "perfect market" concept should be applied as a reasonable approximation, meaning that the product and all products derived therefrom are traded at about short-run marginal cost by competitive equilibrium with no consumers' surplus at the margin.

12. Where prices of non-priced on-forest commodities are not obtainable from off-forest or parallel competitive markets, it may be possible to estimate market equivalent prices from estimated on-forest supply and demand curves. The market equivalent price is determined by equality of marginal WTP (demand) and marginal cost (supply).

13. If the on-forest product is a public good, meaning it is non-rival in consumption, the aggregate demand function is defined differently than for a private good. Because a unit of the good can be used simultaneously by several people, aggregate marginal WTP is the sum of the WTP of the several people. It is the vertical sum of the individual demand curves, given quantity, rather than the horizontal sum, given marginal WTP. The marginal

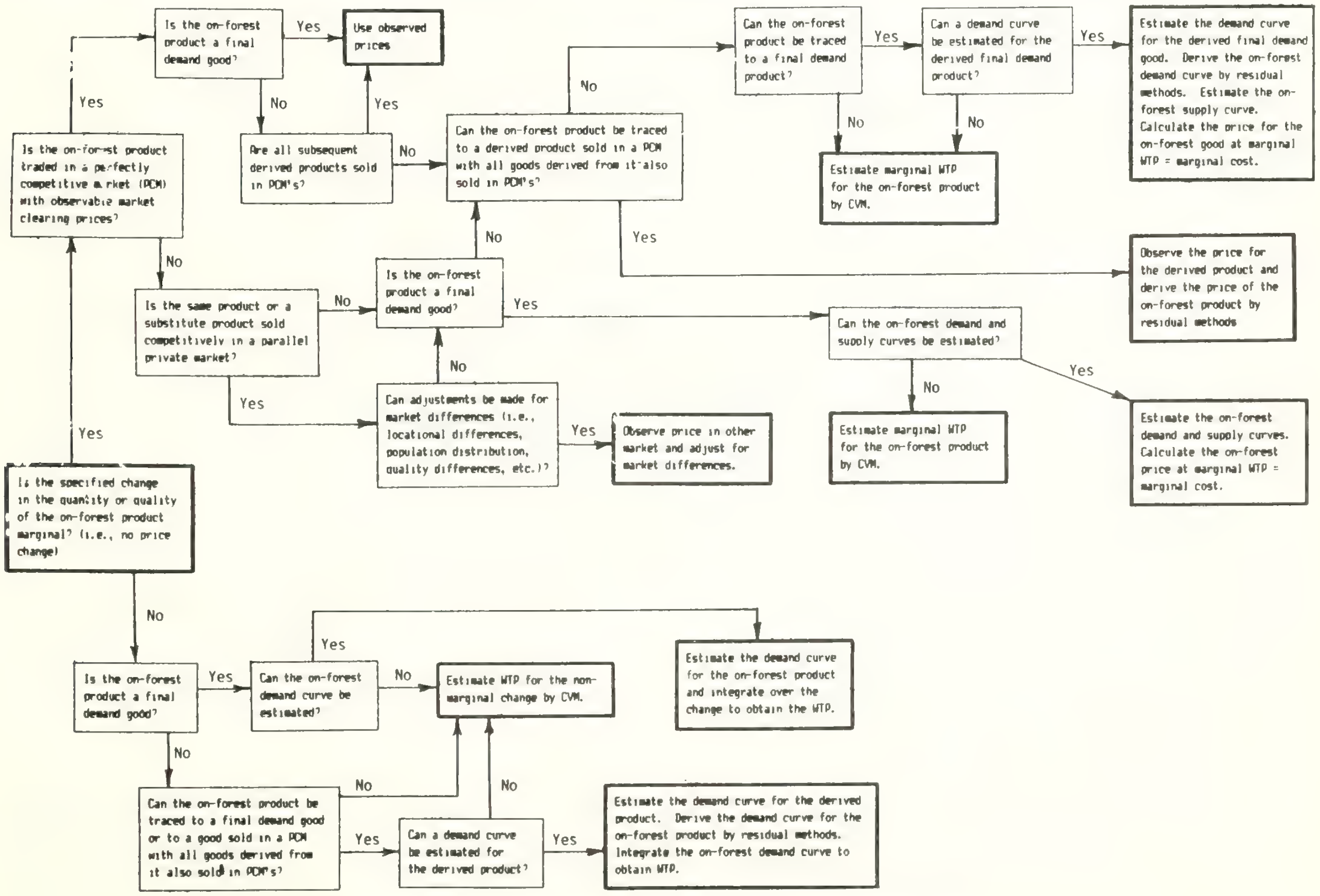

Is the specified change in the quantity or quality of the on-forest product marginal? (i.e., no price change)
Yes
Is the on-forest product traded in a perfectly competitive market (PCM) with observable market clearing prices?
Yes
Is the on-forest product a final demand good?
Yes
Use observed prices
No
Are all subsequent derived products sold in PCM's?
Yes
No
Can the on-forest product be traced to a derived product sold in a PCM with all goods derived from it also sold in PCM's?
No
Can the on-forest product be traced to a final demand product?
Yes
Can a demand curve be estimated for the derived final demand product?
Yes
Estimate the demand curve for the derived final demand good. Derive the on-forest demand curve by residual methods. Estimate the on-forest supply curve. Calculate the price for the on-forest good at marginal WTP = marginal cost.
No
No
Estimate marginal WTP for the on-forest product by CVM.
Yes
Observe the price for the derived product and derive the price of the on-forest product by residual methods
No
Is the same product or a substitute product sold competitively in a parallel private market?
No
Is the on-forest product a final demand good?
No
Yes
Can the on-forest demand and supply curves be estimated?
No
Estimate marginal WTP for the on-forest product by CVM.
Yes
Estimate the on-forest demand and supply curves. Calculate the on-forest price at marginal WTP = marginal cost.
Yes
Can adjustments be made for market differences (i.e., locational differences, population distribution, quality differences, etc.)?
No
Yes
Observe price in other market and adjust for market differences.
No
Is the on-forest product a final demand good?
Yes
Can the on-forest demand curve be estimated?
Yes
Estimate the demand curve for the on-forest product and integrate over the change to obtain the WTP.
No
Estimate WTP for the non-marginal change by CVM.
No
Can the on-forest product be traced to a final demand good or to a good sold in a PCM with all goods derived from it also sold in PCM's?
No
Yes
Can a demand curve be estimated for the derived product?
No
Yes
Estimate the demand curve for the derived product. Derive the demand curve for the on-forest product by residual methods. Integrate the on-forest demand curve to obtain WTP.

Figure 8.—A decision path for estimation of on-forest product value.

value of an additional unit of capacity, therefore, is the sum of the WTP of all people who will use that unit.

14. When a change in the supply of an on-forest product would cause a significant change in the price of that product, nonmarginal valuation methods should be used. The demand-side value of the supply change is, again, net WTP at the forest for the change. This net WTP includes, by definition, consumers' surplus. Such WTP should be calculated by integration of the on-forest demand function over the range of the change.

15. The value per unit of output change in an on-forest product, whether determined for a marginal or nonmarginal change, can be expected to vary among production sites within a region. It should not be assumed that such variation is negligible. Variation among production sites needs to be described to allow decision makers to decide whether the variation is sufficient to cause unacceptable errors.

16. Where available, region-wide off-forest demand curves are useful for valuation of management actions that affect the supply of related on-forest products. Whether it is possible to estimate such curves (or portions thereof) for the region as a whole depends on the nature of the market in the region. If the market is not uniform region-wide, two other possibilities remain. One is to estimate subregional off-forest demand functions that correspond to subregional market areas. The other is to estimate a generalized regional demand model capable of describing price-quantity relationships anywhere in the region. Such a generalized demand model should be specified in terms of substitute prices, supply variables, and demographic demand shifters.

17. For forest products that tend to have only marginal supply changes that can be traced to parallel or derived region-wide competitive markets, the regional demand model is not needed. Here, observed prices and intervening costs, if any, are sufficient. However, prices derived for on-forest products from off-forest markets may vary from place to place in the region, even when the derived competitive market is uniform region-wide.

18. Changes in recreation supply that result in the opening or closing of recreation sites in the presence of excess demand are likely to be nonmarginal, as are capacity changes at congested sites. The nonmarginal nature of such changes in recreation supply derives from the fact that the price of the associated off-forest product, the recreation trip, varies throughout the region (i.e., the price is different at different locations).

19. Given certain assumptions, the on-forest demand function can be derived from the off-forest regional demand function. The on-forest demand curve may be more site-specific than the off-forest demand curve because of variation among locations in extraction and shipment costs and in site characteristics that affect product quality.

20. Depending on the kinds of supply changes contemplated, there may be significant components of net WTP relevant to RPA that are not expressed through normal demand for on-forest products. Option, existence, and bequest value, for example, may be important sometimes. Where it is important, such value should be measured. However, these components of value are not likely to be important for most changes in forest products. They are likely to become significant for actions that alter the populations of threatened and endangered species or which require irreversible major investments of natural resources, such as the addition or elimination of unique wilderness areas or some old growth stands of timber.

21. Past investment decisions may be assumed to have been somewhat inefficient because of incomplete information, imperfect control, and changing conditions or different objectives. Therefore, there should be potential within each region for improved efficiency through reallocation of investments. In any region, there may be many investment and disinvestment opportunities that will alter the supply of forest products. Some of these opportunities are likely to be more productive than others.

22. Given perfect information and control of the future, investments would be made first in the most productive opportunities. Under this ideal condition the notion of a single regional RPA value for each forest product would be nonsense. Instead, a demand schedule for capital would be used to identify each investment opportunity and expose its relative productivity. However, this ideal approach is not realistic because of the expense.

23. If intraregional investment decisions are assumed to be perfectly random (or uniform), the appropriate criterion for allocating investments among regions is the regional average unit value, (with the unit defined at the level of the investment decision, e.g., whole recreation sites or units of capacity at existing sites), and with each investment unit valued at the margin.

24. A realistic assumption is that intraregional investment decisions will be imperfect but will improve somewhat the productivity of forest resources. Under this assumption, a regional average RPA value for each forest product is too conservative. While development of a complete demand schedule of investment and disinvestment opportunities is likely to be prohibitively expensive, it may be reasonable to use a sample of observations to estimate a distribution of net WTP values for each region. Such an estimated distribution contains more information than a regional average value. The sample distribution could be used to estimate criterion values for investment and disinvestment in each region.

25. The economic efficiency objective requires inclusion of significant external costs and benefits. This can be done by incorporating them as "social costs" and "social WTP" in the supply and demand functions used to estimate marginal prices and nonmarginal values, or by adding them to the costs and benefits of management actions.

GR Guidelines and Conclusions

The following guidelines and conclusions are based on the assumption that display of the GR component of the NED value is needed for equity evaluation or assessment of impact on the government budget. The GR component is the price actually paid to the government for the forest product in question. Subtracting the supply cost from this demand price gives net government revenue. It is assumed here that tax revenue is a long-run matter and is not assignable to any given forest product.

1. GR is the demand-side contribution to producers' surplus retained by the government from production of a given forest product. The government's producer surplus is calculated in the same way that producers' surplus is measured for any firm. For joint costs, it may not be possible to separate net GR by forest products. Rather, it may be necessary to calculate net GR for separable management programs. However, GR should generally be separable by forest product.

2. GR is dependent on the pricing policy in effect. Pricing policy is a matter of government choice and may or may not be considered as fixed.

3. If pricing policy is considered fixed and the change to which value is to be assigned is marginal, the GR component of RPA value is the actual price (fee) paid to the government for the given forest product. If the price is zero, GR is zero. Actual fees may or may not be efficient.

4. If existing prices are inefficient and if GR is used as a sole criterion for allocation of public resources, the resulting resource allocation will be inefficient. Possible consequences include behavior of the government as a profit maximizing monopolist, and failure to provide efficient quantities of public goods and services such as wilderness, environmental quality control, etc.

5. If pricing policy is considered variable, the pricing policy to be used must be specified before the GR component can be estimated.

6. Nonmarginal changes that cause price change are valued in terms of the difference in GR before vs. after the change.

CS Account Conclusions

The following comments are based on the assumption that display of the CS account is needed for assessment of impact on final demand.

1. Consumers' surplus represents real national welfare if the justification for value is individual preferences (consumer sovereignty).

2. Consumers' surplus is the NED value less its GR and NPR components.

3. For marginal change with price rationing, the CS-related RPA value is always zero.

4. With nonprice rationing, the CS value may not be zero, even when change is marginal. Therefore, pricing and rationing policy should be evaluated before concluding that CS is zero in the marginal case.

5. For nonmarginal change there is no general value that applies to all situations. The appropriate value is the difference in CS with and without the change. It may be possible to calculate an average unit CS price for a given change that applies to that situation, but it is not likely to be applicable to all other situations.

6. Consumers' surplus is not just an issue with nonmarket goods. Nonmarginal changes in private goods also cause changes in consumers' surplus.

NPR Account Conclusions

The following comments are based on the assumption that measurement of Net Revenue to Private Firms (NPR) is needed to display impact on commerce and industry in the private sector.

1. NPR is the amount by which the real profit of private firms has been increased as a result of the government action in question. As with GR and CS, it is a component of net contribution to NED. It is the demand-side producers' surplus resulting from the action.

2. Demand-side producers' surplus is the NED value less its GR and CS components.

3. With distorted prices NPR may not be zero, even when the government action has only marginal consequences. Therefore, prices should be scrutinized for distortion before concluding that NPR is zero in the marginal case.

4. For nonmarginal change there is no general NPR value that applies to all situations. The appropriate NPR value is the difference in demand-side producers' surplus with and without the change. It may be possible to calculate an average NPR price for a given change that applies to that situation; but it is not likely to be generalizable to other situations.

Conclusions Regarding Equity

The following conclusions are based on the assumption that the equity of resource allocation is an important consideration.

1. Equity is a question about fairness of the effect of a given action on the distribution of income among various accounts.

2. Equity cannot be decided by technical means. It is a political question concerned with the resolution of conflicts among the preferences of separate individuals or groups. To specify a formula by which to judge equity is to preempt political rights by assigning importance weights to different people.

3. If a criterion for judging equity in a given situation has been specified by sovereign authority, either in a command economy by authority of power or by legislation and social contract in a democracy, measurement of the achievement of equity becomes a technical responsibility. However, the definition is likely to be volatile and subject to continual revision in a democracy in which government derives its powers by consent of the governed.

4. Equity can be judged in terms of hypothetical philosophical maxims; but the outcome bears no practical validity unless either the maxim or the judge has sovereign power over all concerned.

5. Without a valid rule for judging equity, the appropriate technical response is impact assessment by which the consequences of a proposed action are exposed effectively to all concerned. Economic impact is an important component of impact assessment. In economic impact analysis the economic consequences of a proposed action are exposed, so that all affected people and institutions can make informed choices regarding their political, litigational, market, or radical response to the proposal.

6. In its pure form, economic impact analysis exposes the net change in the economic well being of each affected interest. It is thus disaggregate measurement of gains and losses, whereas benefit-cost analysis sums these gains and losses to measure aggregate change. The economic impacts may be described in terms of individuals, social and ethnic groups, geographic regions, sectors of the economy, or future generations.

7. Disaggregation of the NED RPA value into GR, CS, and NPR components is one way to assess economic impact. It is exposure of the changes in wealth of the government, final demand, and private industry sectors of the economy. Just as disaggregation of NED into GR, CS and NPR results in three different components as seen from three different points of view, other points of view will lead to still other components.

8. This "pure" form of economic impact analysis is seldom if ever done. Rather, surrogates, such as income, employment, expenditures, etc., are used through tools such as input-output analysis, or public participation and review are used as substitutes for or complements to economic impact assessment.

Summary

An RPA value is the demand-side value for a specific change in the quantity of a forest product at the on-forest point of production. Thus, it is the residual bid, or "willingness to pay," to the land management agency for the management-induced change. The philosophical basis for this notion of value is "consumer sovereignty." The practical basis for this value is free market exchange, whereby something is worth the amount of money for which it is or could be exchanged. The point of valuation is on the forest, or at the point of separation from the forest. The impetus for this value is a change in the output of an on-forest product.

An RPA value is part of an evaluation process to rank policy alternatives characterized by mixes of management activities and associated outputs. The planning model is one of trial and error, in which several alternatives are first designed, then evaluated and ranked. Monetary value in this framework has meaning only in terms of change. The change is the difference between the output level with a base or null alternative and the output with some other alternative. The most practical null alternative for RPA planning is a continuation of current management direction. RPA values are then estimated for the on-forest products whose levels of output differ among the alternatives.

If economic efficiency at the national level is an objective of the evaluation of alternatives, values that measure the demand-side contribution to national economic development (NED) are needed. These values measure the full willingness to pay for the management-induced change. This objective reflects the perspective that the identification of the particular people or groups who receive the benefits of the changes or pay the costs is not at issue. The values measured in terms of contribution to the NED account can be apportioned from the perspective of particular sectors of the economy.

One possible apportionment is among the government, private business, and consumer sectors. If a balanced federal budget is an objective, the contribution to government revenue (GR) is an important consideration. If return to private commerce and industry is an objective, the contribution to net private revenue (NPR) is important. If individual purchasing power (quality of life) is of concern, consumer surplus (CS) is important. Because value from the NED perspective = GR + NPR + CS, disaggregation of NED gains or losses in these three sectors of the economy is one approach to addressing equity considerations.

GR is the demand-side contribution to producers' surplus, or the portion of total willingness to pay retained by the government from production of on-forest products. Subtracting government costs yields the government's producer surplus, which is calculated in the same way as producers' surplus for any firm. NPR + CS is the portion of total willingness to pay for the on-forest product retained by the purchasers, and will be important if a change is nonmarginal, or even for marginal change if consumption is rationed by means other than prices. NPR is the portion that accrues to private firms. CS is consumers' surplus accruing to consumer final demand.

The products to be valued must be specified, and appropriate units of measure must be chosen for each. There is tradeoff here between accuracy and complexity. The products and their respective units should be defined by forest product specialists who understand the processes of production and consumption, the application intended for the values, and the valuation process.

An RPA value for a given forest product can be expected to vary by production location if there are differences in access to markets that result in differences in shipment costs, or if there are differences in local site attributes that cause production and extraction costs to vary from place to place. It would be unusual for a single value to be valid region-wide. Also, there may be opportunities for new investment that are of greater value than some existing operations, such that the RPA value of the most efficient investments is different from the RPA value of the most efficient disinvestments.

To evaluate and rank all the investment and disinvestment opportunities facing a management unit (e.g., a region) is impractical. A more reasonable approach is to evaluate a sample of opportunities and to estimate a distribution of value from that sample. Then, if it is assumed that a management unit will tend to make efficient decisions, the appropriate RPA investment value should be above the average of that distribution, and the appropriate disinvestment value should be below the average. However, if little improvement over random or uniform selection of projects within a management unit is expected, the values should be near the average.

The prices assumed to be in effect for on-forest products will influence returns calculated in the NED, GR, NPR, and CS accounts, and thus the RPA values. It is necessary to decide which prices to use as a basis for estimating RPA values. The most appropriate prices are those expected to be in effect during the planning horizon of the RPA analysis.

There are two basic approaches to estimation of an RPA value: (1) observation of demand in real markets; and (2) observation of demand in hypothetical markets. In either case, marginal and nonmarginal change must be clearly distinguished. A marginal change does not significantly change prices; a nonmarginal change does. For marginal change in the quantity of an on-forest product, the appropriate NED value is the price that would be defined by perfectly competitive equilibrium between on-forest supply and demand, where marginal willingness to pay equals marginal cost. Here only one point in the demand curve is relevant. For nonmarginal change, the value of a supply change is again net willingness to pay for the change; but this must be calculated by integration of the on-forest demand function over the range of the price change. The appropriate NED value is then the per-unit willingness to pay (the total divided by the quantity change).

Because of locational uniqueness or pricing policy, on-forest products are often not sold in competitive markets, and direct estimation of their demand functions is difficult. However, it is often possible to estimate region-wide prices or demand models for derived, off-forest products, such as lumber, red meat, water at point of use, or recreation trips. A properly specified generalized regional off-forest demand model may be capable of describing the demand behavior of any homogeneous subunit of a region, given the parameters of the subunit. Then, subtracting intervening costs from the willingness to pay for the off-forest product yields a valid RPA value for the on-forest product.

Published RPA values should be accompanied by an explanation of the theoretical framework and associated accounting stance for which they were derived. They also should be accompanied by information and procedures for estimating on-forest product values that consider specific decisions and conditions to which published "generic" values are not applicable. Such procedures most likely would include off-forest demand models that could be used at the forest or project level to estimate site-specific values.

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U.S. Department of Agriculture
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Rocky Mountain Forest and Range Experiment Station

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United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-139**

Silvicultural Systems, Cutting Methods, and Cultural Practices for Black Hills Ponderosa Pine

Robert R. Alexander

CLEMSON UNIVERSITY
JUN 23 [illegible]
PUBLIC DOCUMENTS

Abstract

Guidelines are provided to help forest managers and silviculturists develop even- and uneven-aged cutting methods and associated silvicultural practices needed to convert ponderosa pine forests in the Black Hills into managed stands, and maintain them for a variety of resource needs. Guidelines consider stand conditions and insect susceptibility. Cutting practices are designed to maintain water quality, improve wildlife habitat, enhance opportunities for recreation and scenic viewing, and provide wood products.

Cover Photo.—Typical Black Hills ponderosa pine stand.

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Silvicultural Systems, Cutting Methods, and Cultural Practices for Black Hills Ponderosa Pine

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Robert R. Alexander

INTRODUCTION

Black Hills ponderosa pine (*Pinus ponderosa* var. *scopulorum*) (SAF Type 237) (Barrett et al. 1980) occupies about 1.5 million acres in the Black Hills of South Dakota and Wyoming, and associated Bearlodge Mountains of eastern Wyoming (fig. 1). Scattered smaller aggregations of ponderosa pine stands with similar characteristics occupy about 250,000 acres of butte-top and scarp sites to the north and south of the Black Hills and Bearlodge Mountains in Nebraska, Wyoming, and Montana (Boldt et al. 1983).

These forests form a unique, isolated segment of the interior ponderosa pine type. Ponderosa pine, the principal timber species, usually grows in pure, climax stands (Alexander 1974, Boldt and Van Deusen 1974). The main timber-producing stands are the crystalline core area, characterized by rough to rounded hills and divides generally ranging from 4,300 to 6,000 feet (1,310 to 1,830 m) elevation, and the limestone plateau. In the eastern Black Hills, the limestone plateau forms a narrow ridge that occasionally flattens out to narrow uplands with elevations of 3,600 to 4,400 feet (1,095 to 1,340 m); in the western Black Hills, it forms wide, rather level divides separated by narrow, steep valleys that range in elevation from 4,500 to 7,000 feet (1,370 to 2,135 m) (fig. 2).

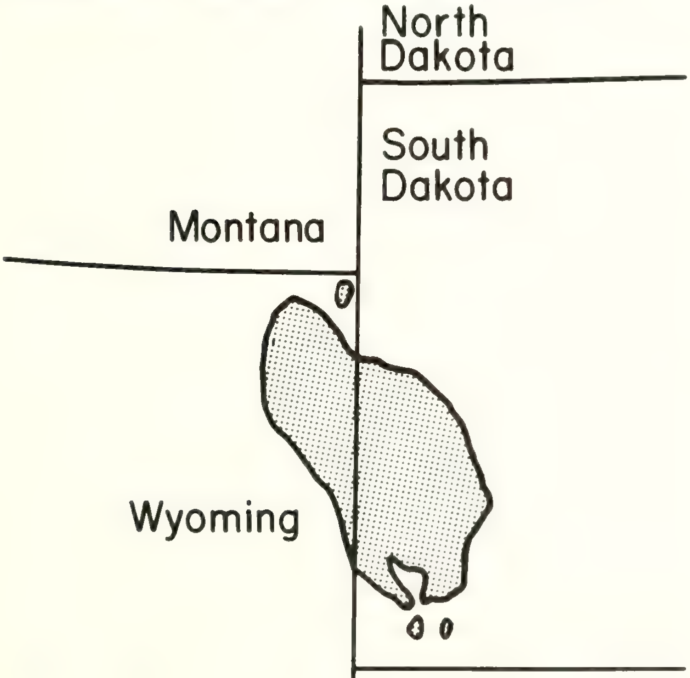

Figure 1.—Occurrence of ponderosa pine in the Black Hills and Bearlodge Mountains (Alexander 1974).

White spruce (*Picea glauca* (Moench) Voss) forms nearly pure, mostly even-aged stands on cool, moist sites where it is considered the climax forest type. Ponderosa pine is seral on these sites. Only about 2% of the commercial forest land currently is dominated by white spruce; but it is gradually replacing seral pine stands on cool, moist sites as a result of fire control, pine-killing insects and diseases, and silvicultural practices. On drier sites, spruce may mix with but eventually is replaced by pine (Boldt et al. 1983). A recently completed study of forest vegetation in the Black Hills and Bearlodge Mountains identified and described 12 forest habitat types. White spruce is the self-reproducing climax tree species on two of these habitat types (*Picea glauca/Vaccinium scoparium* and *P. glauca/Linnaea borealis*).[2]

Stands of quaking aspen (*Populus tremuloides* Michx.) occupy about twice as many acres as white spruce but, for the most part, less permanently. Most aspen stands are seral, replacing pine or spruce only temporarily following disturbance. Stands of bur oak (*Quercus macrocarpa* Michx.) of tree form are confined mostly to low elevation bottoms on the eastern and northern margins of the Black Hills. However, a scrub form of oak also mixes with pine on some upland sites in the northern Black Hills and Bearlodge Mountains. On these sites, if dominant pine cover is lost, because of cutting, fire, or other disturbance, oak brush may occupy the site. Natural replacement of oak by pine is a very slow process; artificial reforestation also is difficult and expensive (Boldt et al. 1983). Aspen has been identified as a climax overstory tree in one habitat type (*Populus tremuloides/Corylus cornuta*), and bur oak in two habitat types (*Quercus macrocarpa-Ostrya virginiana* and *Q. macrocarpa/Symphoricarpos occidentalis*).[2]

Black Hills ponderosa pine forests produce a variety of wood products in large quantities. They also provide forage for livestock and big game; habitats for a variety of wildlife; water for domestic, industrial and agricultural uses; and recreational opportunities for millions of people. Demands on the forest are increasing, and how Black Hills ponderosa pine forests are managed will affect all resources and uses. For example, if timber production is the primary objective, growing stock levels should be high; but forage production and water yields can be increased substantially only at low stocking levels. Carefully planned harvests that maintain low to medium growing stock levels generally are considered appropriate to improve developed recreational opportunities and enhance foreground esthetics. Improvement of middleground and background esthetics generally require open forests, and

[2] *Hoffman, George R., and Robert R. Alexander. Forest vegetation of the Black Hills National Forest of South Dakota and northeastern Wyoming: A habitat type classification. (Manuscript in preparation.)*

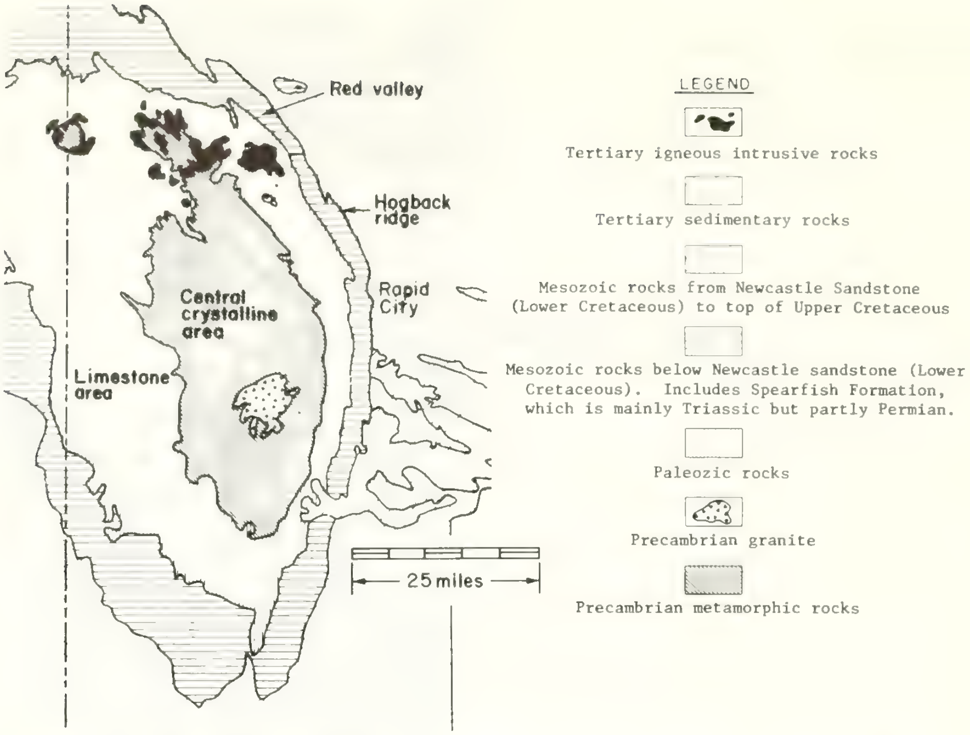
Red valley
Hogback ridge
Rapid City
Central crystalline area
Limestone area
25 miles
LEGEND
Tertiary igneous intrusive rocks
Tertiary sedimentary rocks
Mesozoic rocks from Newcastle Sandstone (Lower Cretaceous) to top of Upper Cretaceous
Mesozoic rocks below Newcastle sandstone (Lower Cretaceous). Includes Spearfish Formation, which is mainly Triassic but partly Permian.
Paleozoic rocks
Precambrian granite
Precambrian metamorphic rocks

Figure 2.—Generalized geologic map of the Black Hills (Boldt and Van Deusen 1974).

stands with both low and high growing stock levels to provide contrasts. Wildlife habitat requirements vary from uncut, a variety of cutover lands, to open forests.

Although land-use planners and land managers must increasingly direct their efforts toward multiple uses, these practices must be based on sound silvicultural principles of the forest type involved. They must understand the tradeoffs between the timber and other resources, as well as physical, social, and economic considerations. The predominance of ponderosa pine seriously limits the diversity in forest vegetation and complicates management efforts to maintain or increase associated forest types (Boldt et al. 1983).

Black Hills ponderosa pine has been managed longer and more intensively than any other Rocky Mountain timber type. Regeneration silviculture has been learned by experience during a century of harvesting that has included all even- and uneven-aged cutting methods. This has led to the conversion of old-growth stands to well-stocked, managed stands of second-growth, with little or no reduction in productivity. Management of Black Hills ponderosa pine is somewhat simplified, because these forests naturally reproduce readily and prolifically, and are free of dwarf mistletoe (*Arceuthobium* spp.) (Boldt and Van Deusen 1974).

Ponderosa pine is the dominant overstory species on seven habitat types (*Pinus ponderosa/Juniperus communis, P. ponderosa/Arctostaphylos uva-ursi, P. ponderosa/Physocarpus monogynus, P. ponderosa/Carex heliophila, P. ponderosa-Juniperus scopulorum, P. ponderosa/Quercus macrocarpa*, and *P. ponderosa/Symphoricarpos albus*).[2]

NATURAL STANDS

Age-Class Distribution

The age-class distribution of ponderosa pine in the Black Hills is in better balance than for any other area or forest type in the Rocky Mountains. Although there are isolated stands in the Black Hills as old as 200+ years, most of the commercial forest land is occupied by stands in the 50- to 130-year-old age classes, with harvesting concentrated in the 50- to 100-year-old age classes (Green 1978). While 57% of the area is stocked with sawtimber-sized stands, only 9% of these stands are classified as old growth. The remaining sawtimber stands (48%) are young, immature to mature sawtimber.

Twenty-six percent of the commercial forest land is in poletimber stands. The stands originated from either wildfires in the late 1800s or early timber harvesting. They vary in density and vigor, depending upon site and whether or not they have been thinned; but most stands have been thinned at least once. About 15% of the Black Hills ponderosa pine is classified as seedling and sapling stands that originated after cutting or fire. Because Black Hills ponderosa pine regenerates easily after cutting and low intensity fires where a seed source remains, only about 2% of the ponderosa pine lands are classified as nonstocked. However, not all nonstocked lands can support ponderosa pine forests, or else they can support only open-grown, low density forests (Green 1978).

Reaction to Competition

Black Hills ponderosa pine is rated shade intolerant (Baker 1948). However, it is not as intolerant as common associates, such as quaking aspen, bur oak, and Rocky Mountain juniper (*Juniperus scopulorum* Sarg.). It is much more intolerant than white spruce, however.

Ponderosa pine is a climatic climax over much of the Black Hills; but fire and logging has converted, partially or completely, some climax ponderosa pine stands to other plant communities—usually aspen or bur oak. In the northern Black Hills on cool, moist sites, ponderosa pine is a long-lived seral to white spruce. Moreover, white spruce has the potential to replace ponderosa pine on many more acres than it now dominates.

Stand Conditions

Ponderosa pine forests in the Black Hills grow in a variety of stand conditions that may vary from irregular, open-grown and poorly stocked to even-aged and overstocked. A common stand condition is two-storied. However, such stands do not occupy as much of the commercial ponderosa pine lands in the Black Hills as in the past. This two-storied structure is a transitory stand condition resulting from repeated partial cutting harvests made from the early 1920s through the 1960s. A few two-storied stands resulted from natural mortality in uncut old-growth stands from the combined impacts of bark beetles, lightning, and wind (Boldt and Van Deusen 1974).

A typical two-storied stand is comprised of a light reserve of mature or overmature sawtimber-sized trees scattered irregularly above a well stocked stand of young trees (fig. 3). Sawtimber stocking in the first story of a typical stand usually will be quite variable, both in amount and distribution. On all but the very best sites, the upper limit of overstory stocking probably will be about 70 square feet of basal area. At higher stocking levels, especially if the trees are distributed uniformly, too few seedlings become established to form a manageable second story (Boldt and Van Deusen 1974).

Large variations in stocking also are common in the second story; but overstocking is the normal condition when overstory basal area is 70 square feet per acre or less. Frequently, the development of the second story has been severely retarded by heavy and prolonged competition from within and above. As a result, it is not unusual to find "reproduction" stands as old as 50 to 60 years that have not advanced beyond large seedling or small sapling size. Trees in such stands generally tend to be slender and whippy, with weak, sparse crowns. The largest and most vigorous trees, or groups of trees, usually are those growing on sites that are least influenced by competition from the overstory. Where overstory stocking is light and irregularly distributed, there may be enough of the better developed trees to form a new stand of fair to good quality after the overstory is removed and the understory is precommercially thinned (Boldt and Van Deusen 1974).

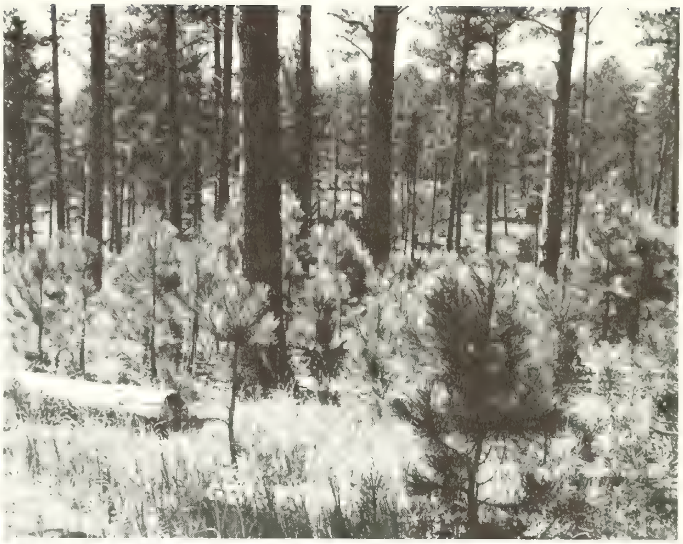

Figure 3.—Transitory two-storied ponderosa pine stand in the Black Hills (Alexander 1974).

Two-storied stands may be pure pine or mixed pine and white spruce. In mixed conifer stands, the first story usually is pine of low to medium density (up to 50 square feet of basal area per acre). The second story is either pure white spruce or a pine-spruce mixture of seedlings, saplings, and small poles, even-aged and well to overstocked. In mixed pine-spruce stands, ponderosa pine usually is a long-lived seral on all but the driest sites.

A little less than one-half of the commercial forest land in the Black Hills is occupied by immature, single-storied ponderosa pine. About 50% of these stands are classified as poletimber. They differ from many even-aged forests, because crown class differentiation tends to be slow and diameter distributions skewed toward the smaller diameter classes. These traits reflect the inherent tolerance of Black Hills ponderosa pine to interstand competition and its tendency to stagnate (Boldt and Van Deusen 1974).

Most of these single-storied stands originated as natural reproduction following heavy harvest cutting, fires, or massive bark beetle epidemics shortly before and after 1900. The remainder has been created by seeding and planting of burns and other deforested sites, and by complete removal of the overstory in two-storied stands.

In stands typically dense at the time of establishment and left to develop naturally, more than 50% of the trees may be expected to remain in diameter classes below the mean stand diameter to biological maturity (fig. 4). Diameters tend to be more normally distributed in stands that have been thinned moderately one or more times (fig. 5).

Single-storied, mature to overmature ponderosa pine stands are represented widely in the Black Hills by many stands that are discrete, but too small in area to warrant separate accounting in inventory. Most of these stands appear to have originated as reproduction following the killing of patches of mature trees in virgin, old-growth stands by bark beetles, localized wildfires, lightning, and wind. Common examples are isolated small patches of yellowbark poles or small sawtimber scattered through a matrix of more extensive two-storied and immature single-storied stands (fig. 6). Typically, these are crowded groups of old-growth trees, which were bypassed in past harvest cutting for saw logs, because of small stem size or poor quality. Some patches have received light intermediate cuts for posts or poles; many others have received no treatment (Boldt and Van Deusen 1974).

Areas in the Black Hills occupied by multistoried stands have increased in recent years. In many cases, these stands have developed as a result of gradual invasion by pine into upland parks and abandoned fields. In other situations, white spruce has invaded ponderosa pine stands. Typically, the stands are composed of several ages of pine seedlings, saplings, and small poles clustered around scattered parent trees. In later stages of the invasion process, clumps of trees may merge to form more or less continuous stands of irregular structure. The openings into which the pines are expanding usually support grasses and forbs, with few shrubs or deciduous trees. Most of these stands are developing on an ecotone. They tend to advance and retreat with cyclic changes in the climate and other environmental pressures. However, in the past 80 years, advances have occurred more often than retreats. Prolonged protection from fire evidently has favored invasion by pine in many upland parks, and white spruce on the coolest and wettest sites.

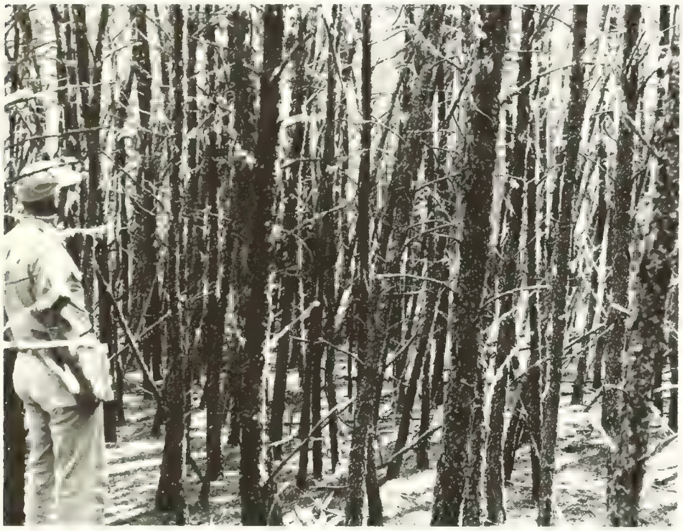

Figure 4.—Stagnated sapling stand; 60 years old; 5,800 stems per acre; average diameter 2.5 inches b.h. (Boldt and Van Deusen 1974).

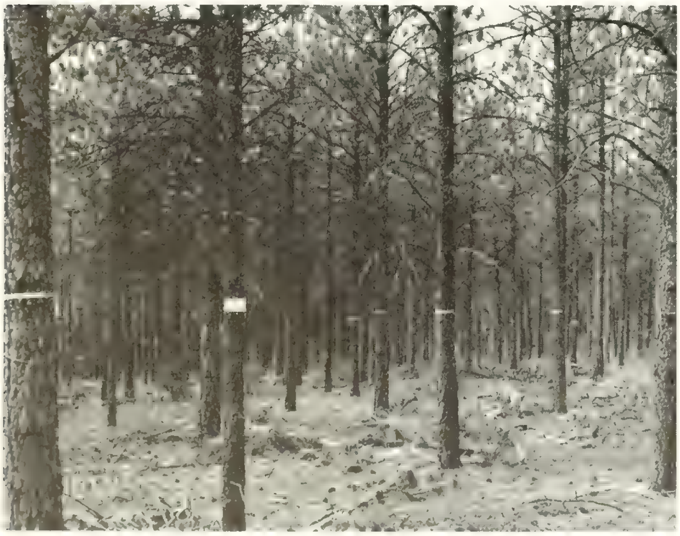

Figure 5.—Even-aged immature ponderosa pine stand; 60 years old; thinned in 1934 and again in 1964 (Boldt and Van Deusen 1974).

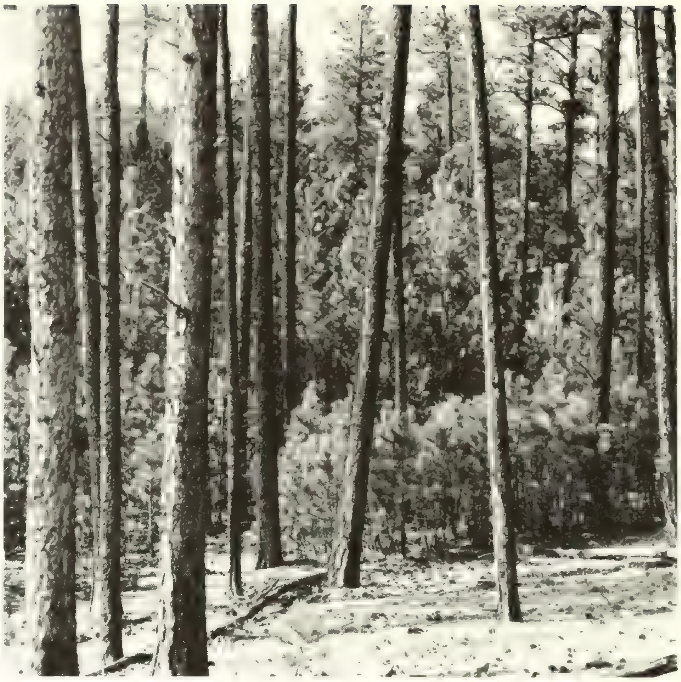

Figure 6.—A mature 150-year-old single-storied stand left uncut by past harvests (Boldt and Van Deusen 1974).

Throughout the Black Hills where heavy cutting of ponderosa pine stands has occurred, a pine-deciduous mixture may exist. Normally, the hardwood component is either aspen or bur oak. Pine usually grows as scattered trees throughout the stand, or may sometimes be found as small pockets of mature trees. Crowns of the scattered pines may be either above or below the relatively low crown canopy of the deciduous species. Because of the seral nature of these mixtures, they range from the early stages of sprouts to full grown oak brush or aspen trees. Fire probably is the most frequent cause, although bark beetles or wind also may be responsible. Occasionally, heavy harvest cutting, which removed most of the pine, provided openings that permitted expansion of aspen or oak by sprouting (Boldt and Van Deusen 1974).

DAMAGING AGENTS

Insects

Bark Beetles

Mountain pine beetle (*Dendroctonus ponderosae* Hopk.) is the only native insect that is capable of devastating Black Hills pine forests. At epidemic levels, this pest has killed entire stands of pine, greatly influencing the distribution of age classes throughout the area. An extremely serious outbreak occurred between 1895 and 1910, destroying an estimated 1 to 2 billion board feet of timber. More recently, serious buildups of mountain pine beetle has occurred in the 1960s and again in the 1970s in the northern hills. Severe and widespread losses were averted by concentrated efforts of insect control crews. During the increase in insect populations to destructive levels, annual pine mortality may exceed 100,000 trees (Thompson 1975).

Adult beetles attack ponderosa pine in midsummer, usually July 15 to September 1 (Schmid 1972). Beetles carry blue-stain fungi that hastens the death of the tree. They create egg galleries, mate, and deposit eggs in the phloem layer. Larvae then feed on the phloem, and in conjunction with blue-stain fungi, girdle and kill the tree. The first indications of attack are pitch tubes on the trunk where the beetles have entered, and brownish dust in the bark crevices and around the base of the tree (fig. 7). Trees severely attacked in the summer die almost immediately but usually do not begin to fade until the following spring. Needles change from green to yellow-green, sorrel, and finally rust brown before dropping off years later. During outbreaks, mountain pine beetles usually kill trees in groups rather than individual trees scattered throughout the stand. These groups enlarge as subsequent generations of beetles continue the infestation, or new adjacent groups may be attacked. Groups may vary from 2 to 3 to 100 or more trees (McCambridge and Trostle 1972).

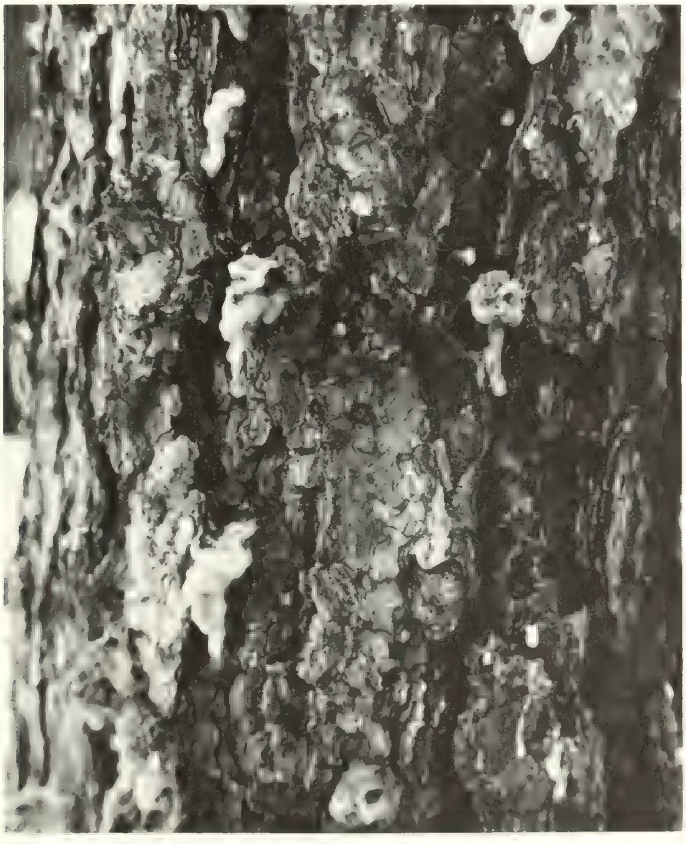

Figure 7.—Pitch tubes on ponderosa pine attacked by mountain pine beetle (Boldt and Van Deusen 1974).

All stands are not equally susceptible to attack. Epidemic outbreaks usually are associated with stands in which average stand diameter is at least 11 inches d.b.h., most of the trees are at least 6 inches in diameter, and stands overcrowded (150 to 260 square feet of basal area per acre) and under stress (Sartwell and Stevens 1975). Infestations usually do not begin in trees smaller than 6 inches d.b.h.; but as groups of trees are killed, smaller trees, intermingled with larger trees, may be attacked and killed. Although natural factors, such as a sudden lowering of fall temperatures or prolonged subzero winter temperatures, nematodes, woodpeckers, and parasites may reduce populations, they cannot be relied upon to control outbreaks (McCambridge and Trostle 1972). Direct control of outbreaks with chemicals is expensive and often only a temporary action until potentially susceptible trees can be cut. High value trees in campgrounds and recreation areas may be protected by preventive sprays. Slash piles covered with clear plastic during warm seasons probably will reach temperatures high enough to afford some control. This treatment is appropriate on small areas, such as around home construction.

The red turpentine beetle (*Dendroctonus valens* LeConte) attacks the base of trees and freshly cut logs and stumps of ponderosa pine (Furniss and Carolin 1977). It is not an aggressive tree killer but frequently weakens trees, making them susceptible to other bark beetles. Populations may increase in areas where logging has occurred for several consecutive years and then may move to adjacent stands. Attacks are characterized by reddish pitch tubes on the lower portion of the stem and heavy frass around the base of the tree. Damage seldom is serious enough to warrant treatment, except in high-value areas. Chemical control is the most effective way to control these beetles.

The pine engraver beetles (*Ips* spp.) also are potentially destructive in sapling and pole stands, although they normally are secondary insects in the Black Hills. Pine engraver populations commonly develop in logging slash, especially if it is shaded or does not dry out quickly. The most effective control is removing or burning large slash and exposing small slash to direct sunlight and wind to dry it rapidly (Sartwell et al. 1971).

Other Insects

Other insect pests generally do not cause widespread losses but can be locally serious. Tip and shoot moth larvae may cause distorted or forked crowns and dead terminal and lateral shoots; sawflies, pine butterflies, and pandora moths can defoliate trees. Control of these insects usually is expensive and difficult.

Diseases

Red Rot

Red rot (*Dichomitus squalens* (Karst.) Reed=*Polyporus anceps* Pk.), which causes a white-pocket rot, is one of the major causes for loss of sound wood in commercial stands (fig. 8). When losses from red rot are combined with those from the brown cubical rots, the percent of scalable defect rises markedly with increasing tree age (Hinds 1971). Both immature and mature, and vigorous and declining trees are susceptible to infection. Even though virtually no economic losses are sustained by immature trees, red rot should be considered a disease of all age classes, except seedlings and saplings (Andrews 1955, 1971).

Infection becomes established in living trees through the branches. Branches larger than 1.5 inches in basal diameter are 20 times more likely to be avenues through which the infection spreads than are smaller branches. Nearly all the decay develops from airborne spores released by fruiting bodies associated with sap rot of dead material. The sporophores continue to develop annually for about 6 years. The spores lodge in small openings in the bark of dead branches and probably germinate immediately if moisture is favorable. After germination, the fungus develops a pad of mycelium between bark and wood, from which the branch wood itself is infected. The infection then spreads toward the bole through both wood and pith of the branch (Boldt and Van Deusen 1974).

Branches can be attacked by red rot fungus from the time they begin to have deadwood (the whole branch need not be dead) until they have been dead about 20 years, provided they have retained their bark. It is very rare for broken, dead branches to become infected. A tree with large, dead, bark-covered branches is a likely candidate for red rot infection. Because infection occurs through dead branches, the possibility of multiple entrance points throughout the whole tree stem increases with age. Once the rot reaches the heartwood, it may spread up and down the trunk and coalesce with other decay pockets. In older trees, the decay may be one long column, many small columns, or a combination of both. There is a lag, however, between the time red rot reaches the heartwood and the development of scalable defect. Hinds (1971) found age classes older than 100 years to have substantially greater percentage of scalable defect due to red rot than younger age classes.

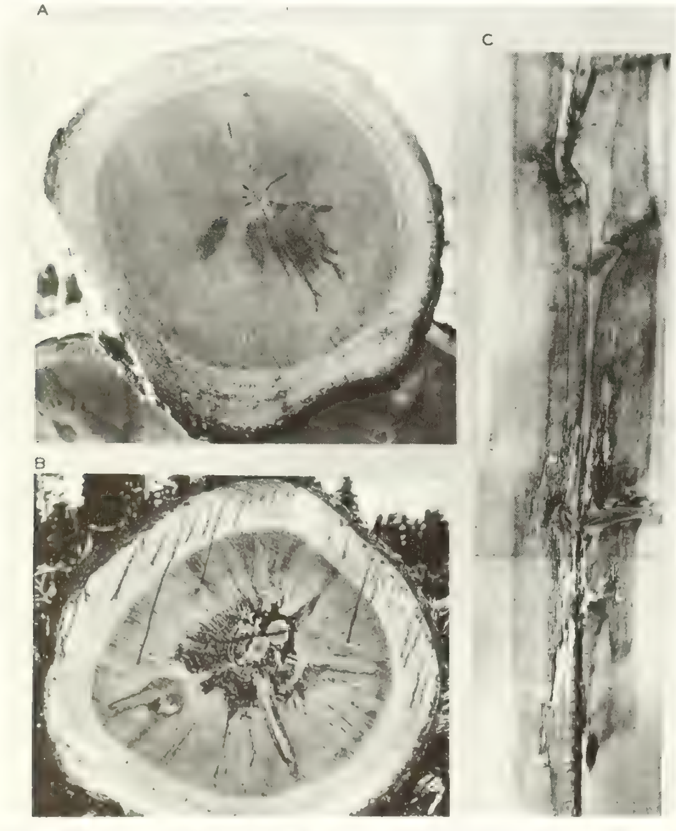

Figure 8.—Red rot in ponderosa pine; (A) incipient decay; (B) advanced decay; (C) advanced decay bordered by incipient decay in heartwood (Boldt and Van Deusen 1974).

Red rot is difficult to detect in living trees, because fruiting bodies rarely develop on them, and then only on dead branches where they merely indicate branch decay. The fungus does not require conspicuous entrance courts, such as wounds, fire scars, or dead tops. No practical method has been found to identify decayed mature and overmature trees and estimate volume losses before cutting (Boldt and Van Deusen 1974).

In immature trees, dead branches generally are reliable indicators of red rot. Undecayed branches resist pressure or break with a crack. Branches in an advanced stage of decay offer little resistance and break as though waterlogged. Suspected branches then must be pruned flush with the trunk to see whether the knots have been penetrated. Heart rot is likely if red rot occurs in the pith. In immature trees, bark-covered branch stubs usually indicate the presence of red rot (Boldt and Van Deusen 1974).

Red rot often can be identified by the characteristic rot pockets that appear in the pitchy base of the branch. Incipient branch decay can be recognized by a continuous white mycelial pad (fig. 9) that binds bark to wood so tightly that pieces of wood stick to the bark when peeled off.

Incidence of red rot infection can be reduced by sound silvicultural practices. Pruning probably is the best cultural treatment in stands where average diameter is small (less than 7 inches d.b.h.). Removing all branches on the butt log in one operation is desirable, although one or more repeat visits may be needed to prune up 17 feet. Pruned branch stubs rarely are the site of red rot infection. The earlier pruning is begun, the more complete will be protection against red rot.

Intermediate cuts to improve volume growth rates also may help reduce the incidence of red rot when infected trees and uninfected trees with many large branches are removed. Stand densities low enough to promote rapid individual tree growth will not necessarily lead to development of large branches (Boldt and Van Deusen 1974).

Western Gall Rust

Western gall rust (*Endrocronarium harknessii* (J. P. Moore) Y. Hiart.) is the second most troublesome disease on Black Hills ponderosa pine, but is a serious problem only in localized areas. Peterson (1959) reported cankers on 7% of the dominant and codominant trees in the Roubaix area. In the Windy Flats area, from one-third to one-half of the potential crop trees had cankers. Nearly all trees at Windy Flats bore galls (often hundreds per tree) that had killed branches and deformed trees. The rust affects the form, lumber content, and growth rate of pines, and kills individual trees, but does not destroy whole stands (Boldt and Van Deusen 1974).

Gall rust infects pine of all ages. It is most serious in plantations, where it may kill young trees. Most infections occur on twigs of the current season. When the rust invades pine bark, cambial cells of the pine shoot begin to divide rapidly. The result is a woody gall, soft at first, but later as resins and other deposited materials solidify, the gall becomes harder and more decay resistant than normal wood. Galls usually live only a few years, because when they produce fruiting bodies (aecia), they disrupt the host bark and often kill the shoots and stems that bear them.

Cankers are formed on the trunks of trees through infections from branches or wounds (fig. 10) and may cause mortality. However, many trees survive and appear to sustain only slight growth loss. Loss of merchantable length and mechanical weakness are the main disadvantages of cankers.

Elimination of the disease from timber stands is not possible. The aeciospores transmit the disease directly from pine to pine, and windborne spores can be disseminated for hundreds of miles. Thinning of trees containing trunk cankers and pruning lower branches that contain galls minimize the adverse effects of gall rust. However, vigorous trees are more likely to be infected than weak ones, partly because the greater surface area of new shoots on faster growing trees provides greater opportunity for infection (Boldt and Van Deusen 1974). There is considerable evidence of natural resistance to gall rust, however. Some trees in a stand have high levels of infection, whereas adjacent trees have fewer or no galls. This phenotypic expression of resistance should be utilized when marking trees to cut or leave.

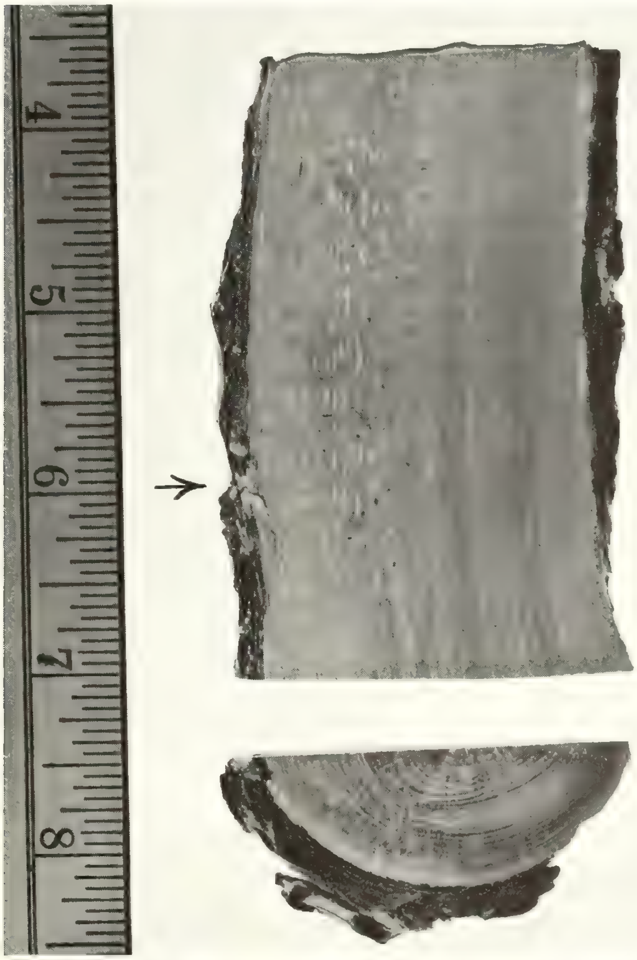

Figure 9.—Cross section of dead branch 2 years after infection by red rot; incipient stage in upper half; advanced stage in lower half (Boldt and Van Deusen 1974).

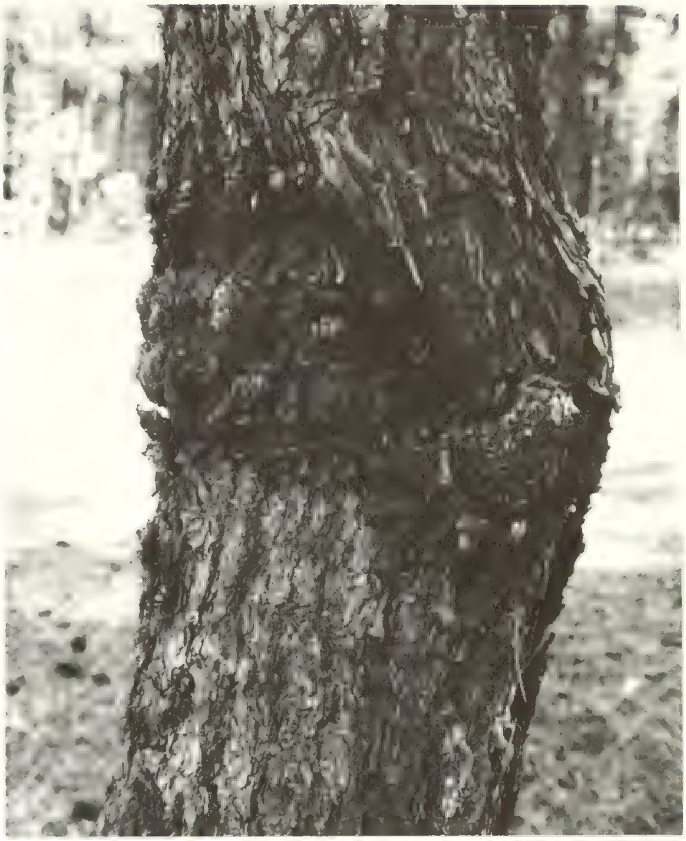

Figure 10.—Gall rust canker on the bole of a Black Hills ponderosa pine.

Dwarf Mistletoe

The Black Hills and Bearlodge Mountains are unique because of the absence of dwarf mistletoe (*Arceuthobium* spp.). Although Black Hills ponderosa pine is susceptible to the disease, the climate will not support the pest. Absence of dwarf mistletoe greatly simplifies the use of cutting methods that depend on natural regeneration.

Other Diseases

Shoestring root rot (*Armillaria* spp.) is common throughout the Black Hills but has caused heavy losses only locally in young plantations, and scattered mortality in sapling and pole-sized trees in thinned stands. Recent research has shown an association of *Armillaria* with mountain pine beetle infested trees in the northern Black Hills (Lessard et al. 1985). The significance of this relationship to management needs further examination.

Infection by shoestring root rot mainly occurs through mycelial strands or rhizomorphs that grow through the soil. Major symptoms of infection begin with a general decline in vigor or abrupt cessation of growth, followed by yellowing of needles and ultimately death of the tree. Whitish mycelial fans, under the bark near ground line, are characteristic evidence of infection. There are no proven methods of direct control (Boldt and Van Deusen 1974).

Needle cast (*Elytroderma deformans* (Weir) Darker) causes brooming and some defoliation on ponderosa pine in the Black Hills, but is not a serious problem. It is found most often on trees in sheltered situations, such as bottoms or in thickets of reproduction. Lower crowns and interiors of pole-sized and larger trees usually are affected. Trees moderately infected with needle cast have reduced vigor and often are attacked by bark beetles (Childs 1967). Open-growing young trees seldom are injured permanently unless the leader is infected repeatedly. Witches' brooms often develop in crowns of trees after several years of light to moderate infection. These brooms have been the basis for several erroneous reports of dwarf mistletoe in the Black Hills.

Fire

The effect of wildfire on the character of ponderosa pine stands depends upon the age and density of the stand and the intensity of the fire. Low intensity ground fires only kill seedling less than 12 inches tall. Larger seedlings, saplings, and poles may be damaged; but older trees are quite resistant. High intensity crown fires destroy all trees in the burned area. Many large trees have fire scars that reduce the value of the butt log. Concentrations of slash and debris, resulting from logging mature stands, can be lopped and scattered, or piled and burned when conditions permit, to reduce the fire hazard and improve esthetic appearance. Dense young stands should be thinned to reduce the probability of crown fires. Fuel breaks should be placed along heavily traveled roads and around high value sites. Visual appearance of these fuel breaks can be enhanced by clipping the residues.

Controlled or prescribed burning in ponderosa pine forests in the Black Hills offers a management opportunity in mature stands without a manageable stand of advanced reproduction. Low intensity surface fires can be used to prepare seedbeds, reduce competing vegetation, and eliminate fire hazards without damage to the residual stand. In stands where advanced pine regeneration has become established before it is needed or wanted, low intensity ground fires can be used to destroy the unwanted regeneration (Boldt and Van Deusen 1974).

Wind and Snow

Ponderosa pine has a well-developed root system and is one of the more windfirm species in the Rocky Mountains. Although wind is not a primary cause of damage to ponderosa pine in the Black Hills, it can be damaging locally, especially in mature to overmature stands during windstorms accompanied by heavy precipitation. Generally, wind risk is not an important consideration in cutting ponderosa pine. Exceptions are dense stands that have developed over long periods of time and do not have the boles and root systems necessary to withstand wind when opened up with a single heavy cut; those topographic situations of very high wind risk, such as ridgetops, upper windward slopes, and saddles in ridges with shallow soils; stands with many trees with defective boles and root systems; and dense stands growing on sites with a high water table.

Stands that are maintained at reasonable densities from seedling size to end of rotation should be much less susceptible to wind and snow damage. Trees in such stands develop sturdier stems and better anchorage in response to gradual increases in stress, and are able to withstand normal wind and snowloads. Snowbend and breakage occurs more often in sapling and small pole-sized trees. Windthrow is more common in large pole and small sawtimber-sized stands (Boldt and Van Deusen 1974).

Animals

Cattle are responsible for most livestock damage. Trampling as the cows walk along plowed furrows is the most common damage. Cattle rarely graze or browse on seedlings. Sheep may browse the tips of very young seedlings. Occasionally cattle will rub on individual small saplings, scraping off bark, and breaking branches and stems. Fencing out livestock until the trees are small saplings is the most practical protection (Boldt and Van Deusen 1974).

Deer (*Odocoleus* spp.) do not ordinarily browse on pine seedlings to the extent that plantation protection is needed. Trees can recover from random browsing with little loss of growth. Initial successes with chemical repellents indicates that long-term protection to pines may be possible (Dietz and Tigner 1968).

About 15 genera of small mammals that eat pine seed are found in the Black Hills and Bearlodge Mountains; but only two, *Microtus* spp. and *Peromyscus* spp., cause serious seed losses. These mice also can cause nearly complete failures among seedlings in plantations by girdling stems under the snow during winter.

Both cottontail (*Sylvilagus* spp.) and jackrabbits (*Lepus* spp.) are known to girdle seedlings or to clip off leaders and succulent branch tips. Frequently, the portion nipped off is not eaten, but is left on the ground near the original plant.

Of all the rodents, porcupines (*Erethizon dorsatum* Brandt) cause the most damage to trees. The trees are never completely immune to porcupine depredations—seedling to sawtimber sizes may be attacked. The most desirable trees, dominant and codominant crown classes, are the ones most often attacked (Van Deusen and Myers 1962). Where porcupine activity is heavy, many plantation trees, not just an occasional individual, have been deformed or killed.

Poisoning probably is the most effective method for controlling rodent losses in seedlings and plantings. Grain treated with compounds such as zinc phosphide, applied at 1 to 3 pounds per acre, apparently offers satisfactory control. In direct seeding operations, the seeds themselves may be coated with rodenticides (Boldt and Van Deusen 1974).

Damage from porcupines and rabbits can be controlled with strychnine-treated salt blocks, installed in bait boxes scattered throughout plantations or natural stands. Bait boxes must be constructed so that larger animals, such as sheep, calves, or deer, cannot be poisoned accidentally. A few losses of squirrels and other animals that are nondestructive to plantations may be unavoidable.

Birds are not known to cause any serious losses of seeds or seedlings in this area. Of the more than 200 species that have been seen in the Black Hills and Bearlodge Mountains, about 30 are known seedeaters. The seasonal bird populations and number of species that favor pine seeds are both small.

Seeds used in direct seeding operations are coated with aluminum powder to make them less subject to bird losses. Some minor seed losses may occur from birds, such as red crossbills (*Loxia curvirostra* Linnaeus) and black-capped chickadees (*Parus atricapillus* Linnaeus) taking seeds out of tree-borne cones. Natural reproduction normally is too abundant for such seed losses to be important.

Sapsuckers (*Sphyrapicus* spp.) sometimes bore into ponderosa pine stems to expose the tender tissues of the inner bark, an important component of their diet.

CUTTING HISTORY

Ponderosa pine forests in the Black Hills have provided a variety of wood products since they were first cut in the mid–1870s. During the past century, most of the area's unreserved and operable forests have been cut over once, and many acres have received multiple partial cuts. Large tracts that were logged free of regulatory restraints—before establishment of the Forest Reserve in 1897—were commercially clearcut and stripped of all trees large enough to produce a railroad tie or mine timber (Boldt and Van Deusen 1974).

After establishment of the Forest Reserve and imposition of rudimentary harvest controls, a few large sales specified cutting of all timber, alive and dead, larger than a minimum diameter limit. Because this approach led to clearing large areas, most subsequent sales made in the next few years required retention of two or more seed trees per acre on each cutover. This type of timber harvesting persisted through the early 1900s, when a two-cut shelterwood was adopted as standard practice.

Beginning in the mid–1920s, individual-tree selection cutting became standard practice. The main reason for this change was to permit rapid coverage of large acreages of overmature timber urgently in need of silvicultural treatment to reduce risk and anticipated mortality. Use of the selection cutting method continued until the mid–1950s, when even-aged management and shelterwood cutting became the standard harvesting practice. Initially, the revised guides called for gradual removal of mature stands in three light cuts spaced 20 years apart, with retention of a few "insurance" trees above the replacement stand for an additional 20 years. On the ground, this conservative version of the standard shelterwood cutting method was barely distinguishable from the individual-tree selection cutting practice that it replaced. In the 1960s, the two-cut shelterwood again became the standard harvesting practice, with timing of the removal cut contingent on establishment and development of the understory. With this change in practice, timber harvesting experience on the Black Hills National Forest returned to where it started at the turn of the century (Newport 1954).

The long history of cutting, together with losses caused by insects, diseases, winds, and fires, nearly has eliminated the original old-growth sawtimber stands on about one-half of the commercial forest area. Only light stands of scattered, old-growth remnants are left on the remaining acres (Boldt and Van Deusen 1974). Despite all of the harvesting and losses to destructive agents, growing stock has not been depleted. In fact, it actually has increased in some instances. Nearly 5 billion board feet of timber has been harvested from the Black Hills.

REGENERATION SILVICULTURAL SYSTEMS

Harvesting practices in the Black Hills evolved largely as a trial-and-error process. However, only in rare instances have past timber harvesting operations been silviculturally damaging. Most cutting has been reasonably successful, as evidenced by the scarcity of poorly or nonstocked acres and the absence of any pronounced reduction in growth or allowable cut during the liquidation of old-growth (Boldt and Van Deusen 1974).

Important lessons learned from these diverse harvesting experiences include: (1) even-aged silvicultural systems are best suited to Black Hills ponderosa pine; (2) within the even-aged system, any of the standard regeneration cutting methods may be a valid option under appropriate circumstances; (3) the shelterwood cutting method offers more advantages and entails fewer disadvantages than either the seed-tree cutting or clearcut methods; and (4) uneven-aged silvicultural systems are not a desirable option for timber production in Black Hills ponderosa pine because of silvical characteristics and stand conditions; but selection cutting methods are valid options in special situations (Boldt et al. 1983).

The objective of each regeneration system is to harvest the timber stand and obtain adequate reproduction. The choice of cutting method in ponderosa pine stands depends upon management goals; but stand conditions, diseases and insect susceptibility, and the risk of potential fire damage that vary from place to place on any area limit the options available for handling individual stands.

EVEN-AGED CUTTING METHODS—MATURE STANDS

This section is limited to mature single- and two-storied pure ponderosa pine or pine-white spruce mixtures.

Multistoried ponderosa pine stands are not considered, because these stands generally have developed as a result of gradual invasion by pine into parks and abandoned fields. If conversion to managed pine is desired, it would require harvesting isolated seed parent trees, site preparation, and planting. Deciduous pine mixtures also are excluded, because in these stands, aspen or bur oak is the dominant stand component. Conversion to pine is difficult and expensive, because it usually is a scattered component. Moreover, the wildlife habitat and scenic beauty values of the hardwood component normally are more valuable than if the stands were converted to ponderosa pine. Management should be directed at maintaining the pine component while increasing the value of the hardwood component.

Management with Advanced Reproduction

Simulated Shelterwood Cutting

This cutting method, generally applicable to transitory, two-storied stands, removes the overstory from a manageable stand of advanced reproduction. It simulates the final harvest of a standard shelterwood.(fig. 11).

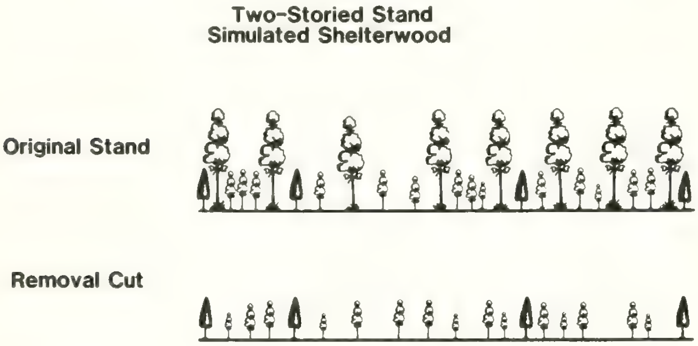

Figure 11.—Sequence of entries with a simulated shelterwood in a transitory two-storied ponderosa pine stand.

Stands may be pure ponderosa or mixed conifer, with a ponderosa pine overstory and either a pine-white spruce or white spruce understory. Understory trees respond to release after cutting; but wide variations in age, composition, quality, and quantity of advanced reproduction require careful evaluation of the potential for future management. One approach is followed if the advanced reproduction is to be managed, another if a manageable stand is not present, cannot be saved, or the manager chooses to destroy it and start over.

Prelogging evaluation.—The initial examination must answer the following questions. (1) How much of the area is stocked with acceptable seedlings and saplings, and will that stocking insure a satisfactory replacement stand? (2) Can it be logged economically by methods that will save advanced reproduction? (3) Is the timber volume too heavy to save advanced reproduction if it is removed in one cut? (4) How much of the area will require subsequent natural or artificial regeneration, either because advanced reproduction is not present or will be damaged or destroyed in logging?

Because any kind of cutting is likely to destroy a portion of the advanced growth (often as much as 50%), a manageable stand of advanced reproduction before cutting should contain at least 600 acceptable seedlings and saplings per acre. Stands or portions of stands not meeting these criteria have to be restocked with subsequent natural or artificial regeneration.

Cutting and slash disposal treatment.—Mature and overmature trees should be cut to release advanced reproduction and harvest merchantable volume. Seed sources need not be reserved from cutting unless required for fill-in stocking. The size, shape, and arrangement of units cut is not critical for regeneration; but to be compatible with major key uses, they should be irregular in shape, with the long axis parallel to the contour to better blend into the landscape.

Protection of advanced reproduction begins with a well-designed logging plan. Logging equipment and activity must be rigidly controlled to minimize damage to advanced reproduction and disturbance to soil. The least damage occurs when skidroads are located at least 200 feet apart and marked on the ground before cutting. Skidding equipment should be moved only on skidroads. Where possible, trees should be felled into openings at a herringbone angle to the skidroad to reduce disturbance when logs are moved onto the skidroad. It may be necessary to deviate from a herringbone felling angle in order to drop the trees into openings. In this case, the logs should be bucked into short lengths to reduce skidding damage. Furthermore, the felling and skidding operations must be closely coordinated, because it may be necessary to fell and skid one tree before another is felled. Dead sound material and snags that are felled should be skidded out of the area to minimize the amount of slash and unmerchantable material left in the woods for subsequent disposal. In stands with heavy volumes per acre, it may be necessary to remove the overstory in more than one cut.

Slash treatment then should be confined to areas of heavy concentrations, as required for protection from fire and insects or preservation of esthetic values. Slash also must be treated carefully to avoid damage to advanced reproduction. If trees are felled into openings as much as possible, a minimum of turning and travel with brush dozers will be needed to concentrate the slash for burning. Slash piles should be large enough to confine burning to the smallest total area possible.

Postlogging reevaluation.—Even with careful logging and slash treatment, some advanced reproduction will be damaged or destroyed. The area must be surveyed to: (1) Determine the extent of damage to the reproduction. At least 300 acceptable seedlings and saplings per acre must have survived to consider the area adequately stocked. Areas that do not meet these standards need fill-in or supplemental stocking. (2) Plan stand improvement—cleaning, weeding, and thinning—to release crop trees. Cutover areas should not be considered in an adequate growing condition until the crop trees are free to grow and the necessary fill-in planting or natural regeneration is complete.

Management for Regeneration After Cutting

Clearcutting

This method harvests the timber crop in one step to establish a new stand. Although clearcutting is an acceptable silvicultural option for mature single-storied and two-storied pure pine and mixed pine-white spruce stands without a manageable stand of advanced reproduction, it has not been widely used in the Black Hills. However, management objectives, such as increasing water yields, creating wildlife openings, and controlling mountain pine beetle, may make the use of clearcuts optimum in some situations in the Black Hills.

If stands are to be clearcut and regenerated naturally, the cut should be made either during or immediately after a good seed crop or the size of the cleared area should be small enough to be within the effective seeding distance of trees around the perimeter of the opening. In the Black Hills, seed dispersal from standing ponderosa pines is limited to about 130 feet. Therefore, openings should be about 260 feet in width where seed producing stands surround the opening, and 150 feet if seeding will be from one side only. Clearcut openings can be in the form of blocks or strips; but to improve the visual appearance, openings with irregular boundaries are preferred with the long axis of the opening laid out along the contour.

Clearcutting has the advantages of allowing the replacement stand to develop free of overstory competition, and there is no risk of loss of an on-site seed source. However, it produces more logging residue than shelterwood cutting and provides little control over competing ground cover. Moreover, the probability of natural regeneration establishment is reduced if success depends upon seedfall from trees harvested on the area, especially if large openings are cut.

Shelterwood Cutting

This method harvests a timber stand in a series of cuts. It is applicable to single-storied ponderosa pine or two-storied pine or mixed conifer stands without a manageable stand of advanced reproduction. In a standard shelterwood, the new stand regenerates under the shade of a partial overstory canopy. The final harvest removes the shelterwood and permits a new stand to develop. Group shelterwood (a modification of the shelterwood method) is applicable in stands composed of irregular mosaics of small even-aged groups or patches of trees. The new stand regenerates in small openings that leaves trees standing around the margins as a seed source. Openings are too small (2 acres or less) to be classified as a clearcut (USDA Forest Service 1983). This kind of cutting has been incorrectly called a modified group selection, but differs from a selection cut in the way the growing stock is regulated.

Standard shelterwood is the preferred even-aged option for ponderosa pine in the Black Hills. Shelterwood cutting requires careful marking of individual trees or groups of trees to be retained and close supervision of logging. The following recommendations for shelterwood cutting practices are keyed to broad stand descriptions based largely on experience and insect problems (Boldt and Van Deusen 1974, Boldt et al. 1983). Stands are pure pine unless otherwise indicated.

Mature single-storied stands.—These stands may appear to be even-aged but often contain more than one age class (fig. 12). Codominants form the general level of the canopy; but the difference in height between dominants, codominants, and intermediates is not great. Stocking varies from uniform to irregular.

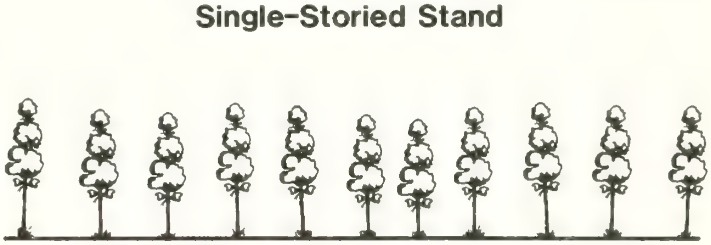

Figure 12.—Single-storied stand—not a common occurrence in Black Hills ponderosa pine.

Because mature single-storied ponderosa pine stands in the Black Hills only occupy small areas in any locality, they should be handled according to the treatment prescribed for a transitory two-storied stand without a manageable understory of advanced reproduction. However, when trees in these inclusions are considerably larger than trees in the matrix stand, it is desirable to limit harvesting in the single-storied stand to a sanitation salvage until trees in the surrounding stand reach about the same size as trees in the inclusion. After stand sizes have equalized, the included stand should be opened gradually to match the stocking of the matrix stand, and then may be treated similarly to the end of the rotation.

If the inclusion is small (2 acres or less) and occurs in a two-storied stand with a manageable stand of seedlings or small saplings in the second story, it normally would be given a removal cut 10 to 20 years before the final harvest that removes the overstory in the matrix stand. If the inclusion is larger than 3 acres, it should be given a shelterwood seed cut. The overwood should be removed at the same time as the final harvest in the two-storied matrix stand. If the inclusion is 3 acres or less, another regeneration option is a clearcut, with seeding from the side by overstory trees in the matrix stand.

Mature two-storied stands.—These stands appear to be two-aged but may contain more than two age classes (fig. 13). The top story resembles a single-storied stand. The second story is composed of younger trees of smaller size. If the stand is more than two-aged, either or both the top story and second story may contain more than one age class.

In mixed conifer two-storied stands, the overstory usually is pure pine. The second story is seedling- and/or sapling-size pine and white spruce or white spruce only. Stocking in both pure and mixed stands varies from uniform to irregular. However, stocking in the second story is not sufficient to provide a replacement stand when the overstory is removed. The manager has the option of either saving as much of the advanced growth as possible and supplementing it with subsequent regeneration or destroying the advanced growth and starting over. In most situations, the first option has been chosen.

A two-cut shelterwood usually is appropriate in stands that have been entered previously. A three-cut shelterwood often is more desirable in stands not entered previously or only lightly entered, especially in stands with a large white spruce component, because spruce is susceptible to windthrow.

Using a two-cut shelterwood, the first cut normally will remove between 50% to 60% or more of the basal area (fig. 13). This is the seed cut. Trees retained should be in vigor classes A and B insofar as possible, but selected dominants and codominants can be left if needed to maintain the residual BA, even when they are in vigor classes C and D, if they do not have dead or dying tops. Good crowns and evidence of past cone production are characteristics of good seed trees. Avoid cutting holes in the canopy by distributing the cut over the entire area. In mixed conifer stands, if the top story is pure pine, handle as a pure stand. If the top story is of mixed conifer composition, a choice must be made as to which species is to be favored in the regeneration. To favor white spruce, lighter cuts (40% to 50% of the BA) that remove as much of the pine as possible are recommended. To favor ponderosa pine, heavier cuts (60% to 70% of the BA) that retain as much of the pine as possible are recommended.

The second entry should be the final harvest to remove the remaining original stand and release the reproduction. It cannot be made until the new stand of reproduction is established. Normally, this will be between 5 and 20 years after the seed cut.

The manager has other options, including cutting less than the recommended basal area, making more entries, and spreading the cut over a longer time by delaying the final harvest until the new stand is tall enough to create the appearance of a high forest. This is not recommended where mountain pine beetles limit how stands can be managed. Moreover, delaying the final harvest is not likely to be cost effective.

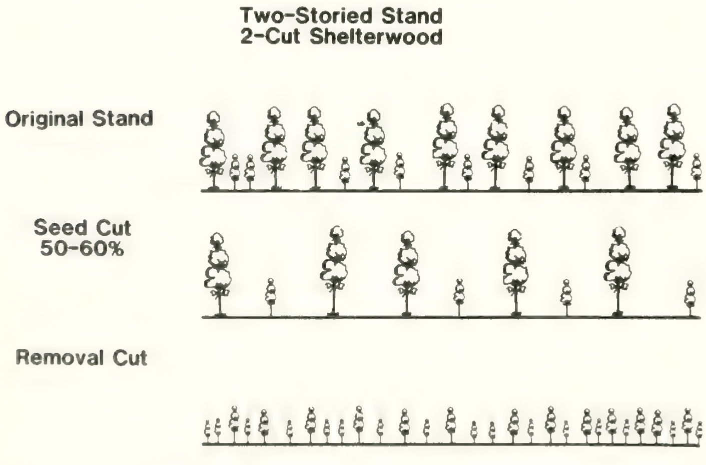

Figure 13.—Sequence of entries with a two-cut standard shelterwood in a two-storied ponderosa pine stand.

Using a three-cut shelterwood, the first entry should remove 30% to 40% of the basal area on an individual-tree basis (fig. 14). This initial entry is a preparatory cut, because it probably does not open up the stand enough for a significant amount of pine reproduction to become established. The general level of the canopy should be maintained by removing some trees in each overstory crown class. The cut should come from the poorest vigor class trees; but openings larger than one tree height in diameter should be avoided by distributing the cut over the entire area. In mixed conifer stands, a three-cut shelterwood will tend to favor white spruce, because it will begin to regenerate under the preparatory cut.

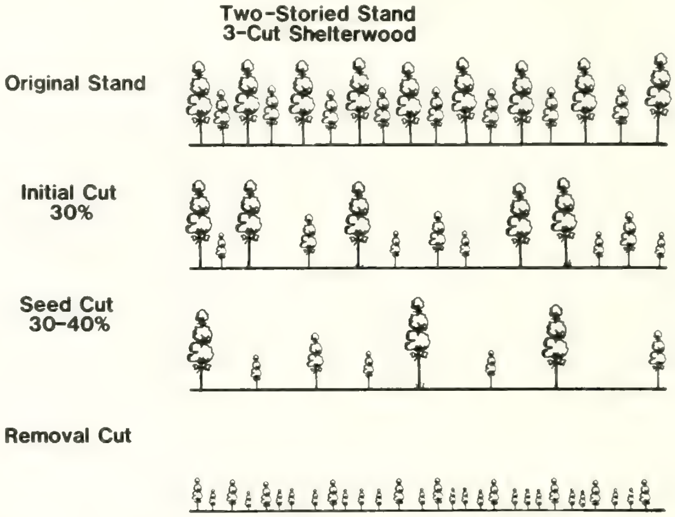

Figure 14.—Sequence of entries with a three-cut standard shelterwood in a two-storied ponderosa pine stand.

The second entry into the stand can be made 5 to 10 years after the first cut. This is the seed cut and should retain 30 to 50 square feet of basal area or remove 30% to 40% of the original basal area. This cut opens up the stand so that pine regeneration can become established. The largest and most vigorous dominants and codominants should be reserved as a seed source; but avoid cutting openings in the canopy larger than one tree height in diameter by distributing the cut over the entire area, even if it means leaving trees in the C and D vigor classes with poor seed production potential. In mixed conifer stands, heavier cuts that retain as much of the pine as possible will favor pine in the replacement stand, whereas lighter cuts that retain more white spruce will favor spruce in the replacement stand.

The last entry into these stands is the final harvest that should remove all of the remaining original overstory. It should not be made until a manageable stand of reproduction has become established; but the cut should not be delayed beyond this point, because the overwood hampers the later growth of the seedlings, and saplings tend to be more easily damaged by the removal.

The manager also has the option of removing less than 30% of the basal area at any entry and making more entries; but they should not be made at more frequent intervals. The cut will be spread out, and continuous high forest cover will be maintained for a longer time. This option is not recommended where either mountain pine beetles or economics limit how stands can be handled.

Openings may occur naturally in regenerated two-storied stands. In other clumpy or irregularly-spaced stands, openings may have resulted from the break-up of stands associated with beetle attacks, fires, or logging. For stands where managers wish to retain clumpy or irregular spacing, either a two- or three-cut group shelterwood is an option.

With a two-cut alternative, the first cut can remove between 40% to 50% or more of the basal area in a group shelterwood (fig. 15). The group openings can be two or three times tree height; but the area cut over should not exceed about one-half of the total. Openings should be irregular in shape to simulate natural openings. One additional entry can be made in the stand to remove the remaining original basal area in group openings up to two to three times tree height.

With a three-cut alternative, the first entry should remove about 30% of the basal area using a group shelterwood (fig. 16). Openings should be kept small and conform to the natural arrangement of the stands, with not more than one-third of the area cut over at any one time. The second entry into the stand should not be made until the first openings have been regenerated. This cut removes about 30% to 40% of the original basal area without cutting over more than an additional one-third of the area. The final entry should remove the remaining groups of merchantable trees.

With both alternatives, the timing of the final entry depends on how the manager decides to regenerate the openings. Using natural regeneration, the final harvest either (1) must be delayed until the trees in the original openings are large enough to provide a seed source, (2) harvesting follows a good seed year on site, (3) these openings are planted, or (4) a standard shelterwood is applied to the last groups. In the last case, it will require at least one additional entry to remove the overstory after reproduction has established.

With either alternative, the manager may choose to remove less than the recommended basal area and cut over less than the recommended basal area at any time. This will require more entries and spread the cut over a longer time, but each new cut should not be made until the openings cut the previous entry have regenerated. Furthermore, the last groups cannot be cut until either there is sufficient seed on site from the trees harvested, an outside seed source, the openings are planted, or a standard shelterwood is applied to the last groups.

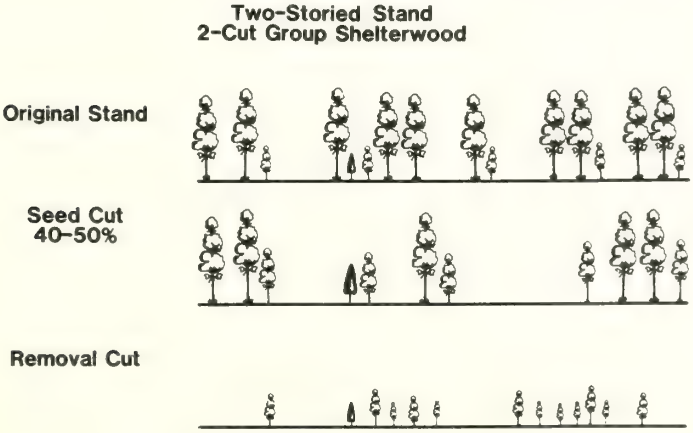

Figure 15.—Sequence of entries with a two-cut group shelterwood in a two-storied ponderosa pine stand.

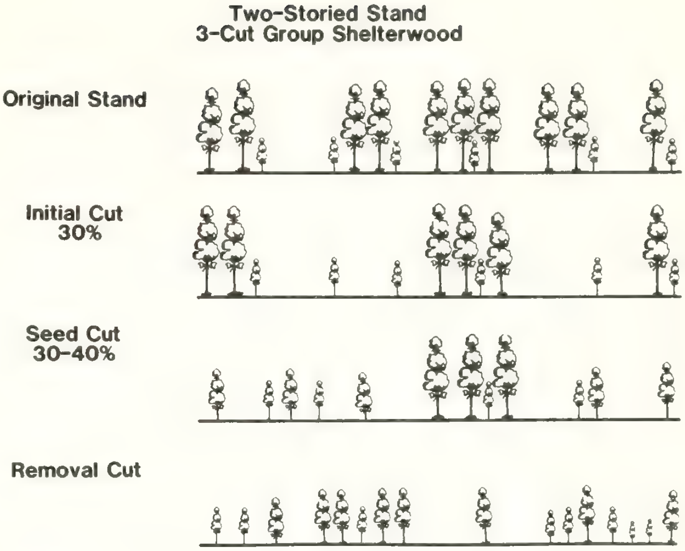

Figure 16.—Sequence of entries with a three-cut group shelterwood in a two-storied ponderosa pine stand.

Group shelterwood cutting is not applicable in pure pine stands where mountain pine beetles impose limitations, because the interval between initial cutting and final harvest is likely to be too long to prevent serious loss of beetle-susceptible trees.

Modifications for insect problems.—Mountain pine beetles have killed extensive amounts of unmanaged ponderosa pine, particularly in dense, single-storied second-growth stands in the northern Black Hills. Extensive tree-killing has been associated with stand densities ranging from 150 to 260 square feet basal area per acre and mean tree diameters of about 11 inches d.b.h. and larger (Sartwell and Stevens 1975).

If mountain pine beetle is present in the stand at an endemic level or in adjacent stands at epidemic levels and less than the recommended basal area to be removed in the first cut is in susceptible trees, any attacked trees and all of the most susceptible trees should be removed in the first cut. This will include most of the larger diameter trees in mature single- and two-storied stands. Dense stands of understory trees and young and immature groups and patches should be thinned. In immature single-storied stands, most of the trees will be in the susceptible category. Although generally the larger the diameter the greater the susceptibility, current knowledge does not permit differentiation of tree susceptibility when diameters are all about the same. In this case, leave trees should be dominants of good vigor with potential for seed production. Provision should be made to salvage attacked trees. Moreover, the second cut should be made within 5 to 10 years after the initial cut.

If more than the recommended basal area to be removed in the first cut is in susceptible or attacked trees, the manager has three options: (1) remove all the trees in single- and two-storied stands, followed by thinning in dense young stands, patches, or groups; (2) remove the recommended basal area in attacked and susceptible trees, thin the dense stands, patches, and groups of young immature trees, and accept the risk of future losses; or (3) leave the stand uncut. However, the benefits of thinning are not likely to be realized if the thinned area is small and surrounded by unthinned stands sustaining an attack. If the stand is partially cut or left uncut, some trees in the smaller diameter classes will survive.

If a single- or two-storied stand is sustaining an increasing or epidemic infestation and the manager chooses to either partially cut or leave the stand uncut, there is a risk of an outbreak that could destroy most of the infested merchantable stand and spread to adjacent stands.

Time of cutting is important in reducing attacks by *Ips* and turpentine beetles. While it is unlikely that sawlog cutting operations can be shut down during attack periods, thinning operations can be scheduled for times of minimum activity, preferably after September 1.

Cutting to save the residual stand.—In shelterwood cutting, protection of the residual stand from logging damage is a primary concern. The residual stand includes merchantable trees left after standard shelterwood, reproduction established after the seed cut in standard shelterwood, and reproduction established after each cut in group shelterwood. Before the final harvest is made with standard shelterwood and before each entry with group shelterwood, the manager must determine if there is an acceptable stand of reproduction. Furthermore, the stand must be reevaluated after final harvest in standard shelterwood and after each entry with group shelterwood to determine the need for supplemental stocking. The same criteria used to evaluate advanced reproduction with a simulated shelterwood applies here.

Protection begins with a well-designed logging plan at the same time of the first cut. To minimize damage, the same protection measures for management with advanced reproduction apply here.

Slash disposal and seedbed preparation.—Some treatment of logging slash and unmerchantable material may be needed after each cut, especially if *Ips* populations are observed. Treatment should be confined to concentrations and that needed to reduce visual and insect impacts. Piling and burning slash may cause damage to the residual stand and is expensive and time consuming. Spot burning usually is more effective if stands are open and slash accumulations are kept away from residual trees. Treatment in stands often can be limited to lopping and scattering, chipping along the roadway, and hand piling and burning to minimize damage, especially where utilization of small material for small posts and firewood removes much of the slash (fig. 17). In group shelterwood cutting, if there is not a manageable stand of advanced reproduction, dozers equipped with brush blades can be used to concentrate slash for burning in the openings. Piles should be kept small to reduce the amount of heat generated.

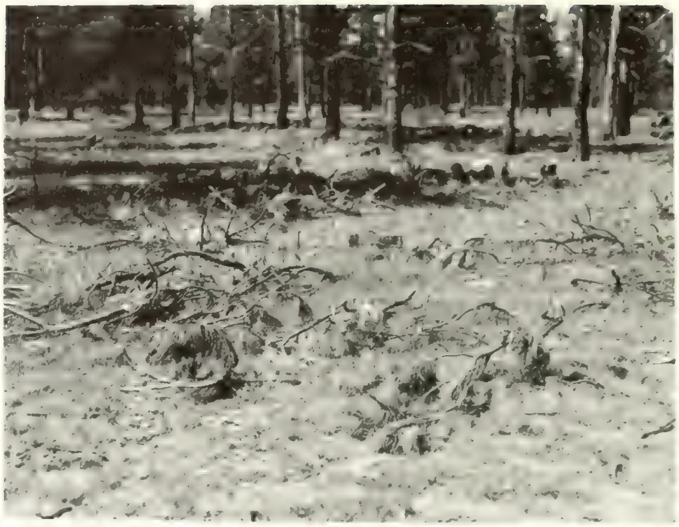

Figure 17.—Sequence of entries with a seed-tree cutting in a two-storied ponderosa pine stand.

On areas to be regenerated by new reproduction, a partial overstory canopy or trees standing around the margins of small openings provide two of the basic elements necessary for regeneration success—a seed source within effective seeding distance and an environment compatible with germination, initial survival, and seedling establishment. The manager must make sure that the third element—a suitable seedbed—is provided after the regeneration cut where standard shelterwood cutting is used, and after each cut where group shelterwood or cuttings to convert irregular stand structures to managed stands is used.[3] In the Black Hills and Bearlodge Mountains, logging disturbance usually is adequate for site preparation. In stands with heavy fuel loading, prescribed burning is a successful site preparation method.

Seed-Tree Cutting

This method harvests nearly all of the trees on an area in one cut. A few of the better trees are left well distributed over the area to reseed naturally. Seed trees may or may not be harvested after regeneration is established.

Seed-tree cutting is an acceptable silvicultural option in mature single-storied and two-storied pure pine and mixed conifer stands without a manageable stand of advanced reproduction. Many acres of Black Hills forests have been harvested and successfully regenerated by this method (Boldt and Van Deusen 1974). In both single-storied and two-storied stands, the first cut should be heavy, removing about 90% or more of the residual volume. The light reserve stand normally will contain five to ten trees per acre to reseed the area (fig. 18). The residual stand then is cut after the area is regenerated.

Seed-tree cutting has advantages over shelterwood cutting. The seed trees offer less overstory competition to the development of the replacement stand; removal of seed trees is likely to result in less damage to the replace-

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[3] *Discussion of the silvical requirements and cultural practices necessary for successful ponderosa pine regeneration in the Black Hills is beyond the scope of this paper. For this information, see Boldt and Van Deusen (1974).*

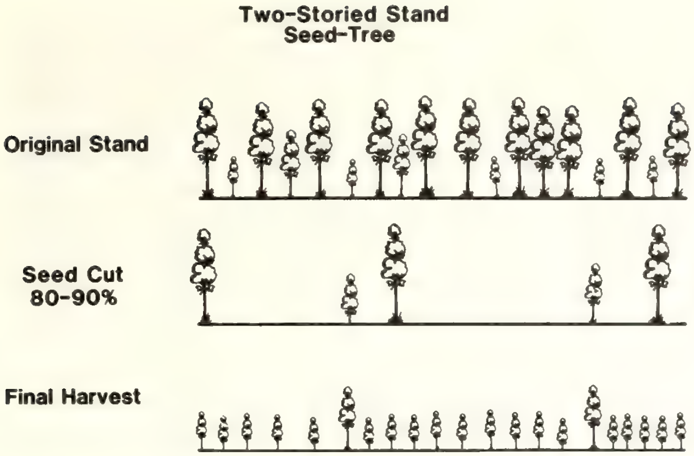

Figure 18.—Utilization of all usable material, including firewood, can minimize the need for slash disposal.

ment; and because there are fewer seed trees, there is less likelihood of an overly dense replacement stand. However, the heavy first entry usually leaves a large amount of logging residue that is both unsightly and a fire hazard. Moreover, leaving only a few seed trees risks the loss of seed source, especially in densely grown stands. Trees that have developed together over long periods of time mutually support each other and are vulnerable to windthrow and windbreak when suddenly fully exposed to the wind. The limited overstory competition that is favorable to the development of tree seedlings also favors the development of undergrowth. Consequently, the site may become occupied by shrubs, graminoids, and forbs at the expense of seedlings.

Procedures outlined for cutting to save the residual stand, slash disposal, and seedbed preparation for shelterwood cutting methods should be followed here.

UNEVEN-AGED CUTTING METHODS—MATURE STANDS

Single- and two-storied ponderosa pine stands are best maintained under even-aged cutting methods, preferably some form of shelterwood. However, these stands may occur as uneven- to broad-aged by even-aged groups and patches. Moreover, uneven-aged management may be more compatible or desirable for some management objectives or resource needs. For example, the impact on the forest should be as light as possible in areas of steep topography and erosive soils or where management goals include maintenance of continuous forest canopy, vertical diversity, etc. Uneven-aged management may be more appropriate for these conditions and goals.

Uneven-aged management includes cultural treatments, thinnings, and harvesting necessary to maintain continuous high forest cover, provide for regeneration of desirable species, either continuously or at each harvest, and provide for controlled growth and development of trees through the range of size classes needed for sustained yield of forest products. Managed uneven-aged stands are characterized by trees of many sizes intermingled singly or in groups. Cutting methods do not produce stands of the same age that are large enough to be recognized as a stand. Forests are subdivided into recognizable units that can be located on the ground on the basis of timber type, site, logging requirements, etc., rather than acreage in stand-age classes. Growing stock is regulated by setting (1) a residual stocking goal, in terms of basal area or volume, that must be maintained to provide adequate growth and yield; (2) a diameter distribution goal that will provide for regeneration, growth, and development of replacement trees; and (3) a maximum tree size goal. In addition, a decision must be made on how to handle small trees. Both individual-tree selection and group selection cutting methods can be considered in stands with irregular to all-aged structure (Alexander 1986; Alexander and Edminster 1977a, 1977b).

Individual-Tree Selection Cutting

This regeneration cutting method harvests trees in several or all diameter classes on an individual basis. Stands regenerate continuously. The objective is to provide a stand with trees of different sizes and age classes intermingled on the same site (USDA Forest Service 1983). Choice of trees to be cut depends on their characteristics and relationship to stand structure goals set up to regulate the cut. This cutting method provides maximum flexibility in choosing trees to cut or leave, and is appropriate only in uniformly spaced stands with irregular to all-aged structure. However, because of ponderosa pine's silvical characteristics, individual-tree selection cutting is difficult to implement and maintain in pure stands. In mixed pine-white spruce stands, it is a better option; but few pines are likely to establish after the initial cutting.

Group Selection Cutting

This regeneration cutting method harvests trees in groups ranging from a fraction of an acre up to about 2 acres (USDA Forest Service 1983). It is similar to a group shelterwood, except in the way the growing stock is regulated. The area cut is smaller than the minimum feasible for a single stand under even-aged management. Trees are marked on an individual-tree basis; but emphasis is on group characteristics, which means trees with high potential for future growth are removed along with trees with low growth potential. Loss in flexibility is offset partly by the opportunity to uniformly release established regeneration and reduce future logging damage. When groups are composed of only a few trees, the method can be used together with individual-tree selection cutting in mixed stands. This cutting method is most appropriate in irregular to broad-aged mixed or pure multistoried ponderosa pine stands that are clumpy, groupy, or patchy. However, it can be used in uniformly spaced stands with the size, shape, and arrangement of openings based on factors other than the natural stand conditions (Alexander 1986; Alexander and Edminster 1977a, 1977b).

Stand Structure Goals

Control of Stocking

The first step in applying a selection cut to a ponderosa pine stand is to determine the residual stocking level to be retained. Because total stand growth for many species under uneven-aged management does not differ greatly over the range of stocking levels likely to be management goals, stocking levels set near the lower limit, where no growth is lost, concentrate increment on fewest stems. This reduces time required to grow individual trees to a specific size and requires a minimum investment in growing stock (Alexander and Edminster 1977b).

The residual stocking level with the best growth potential and most desirable appearance in pure or mixed ponderosa pine stands varies with species composition, management objectives, productivity, diameter distribution, etc. In old-growth ponderosa pine stands, stocking usually varies from 60 to 180 square feet of basal area per acre in trees in the 4-inch and larger diameter classes. Basal areas above 150 square feet per acre probably represent overstocking. While no guidelines are available for uneven-aged stands, residual stocking levels of GSL 60 to 160 are suggested for managed even-aged stands, with the site quality normally associated with ponderosa pine in the Black Hills (Alexander and Edminster 1981). These levels should be useful in estimating initial residual stocking goals, in terms of square feet of basal area per acre, for that part of the stand that eventually will be regulated under uneven-aged management (Alexander 1986, Alexander and Edminster 1977b).

While these general recommendations probably are adequate to start with, use of yield tables for even-aged stands in setting stocking goals for uneven-aged stands assumes there is little difference between the growing stock of the two other than a redistribution of age classes over a smaller area (Bond 1952). This may be true when stands without a manageable understory of advanced growth are harvested by a group selection method. The result is likely to be a series of small even-aged groups represented in the same proportion as a series of age classes in even-aged management. If advanced growth of smaller trees has become established under a canopy of larger trees, however, a different structure may be developed with either individual-tree or group selection methods. Growth space occupied by each age or size class is being shared (Reynolds 1954). Assuming that damage to understory trees resulting from removal of part of the overstory trees can be minimized, advanced growth will successfully establish a series of age classes on some areas. In this situation, more trees of a larger size can be grown per acre than with a balanced even-aged growing stock (Bourne 1951, Meyer et al. 1961). Nevertheless, without better information, the residual stocking goals set for even-aged management are the best criteria available.

Maximum Tree Size

The second item of information needed is the maximum diameter of trees to be left after cutting. In old-growth ponderosa pine stands in the Black Hills, maximum diameter usually varies from 16 to 26 inches d.b.h., depending on stand density, site quality, species composition, etc. Examination of plot inventory information from unmanaged stands with irregular stand structure suggests that a diameter of 16 to 18 inches can be attained within the time period generally considered reasonable under the narrow range of site quality found in the Black Hills and stocking levels likely to be management goals (GSL 60 to 120). Without information on growth rates in uneven-aged stands or rates of return for specific diameter stocking classes, a 16-inch maximum diameter seems a reasonable first approximation to set for timber production on lands of average site quality. Trees of larger diameter with a lower rate of return on investment may be appropriate for multiple-use purposes (Alexander 1986, Alexander and Edminster 1977b).

Control of Diameter Distribution

Control over distribution of tree diameters also is necessary to regulate yields under uneven-aged management. This most important step is accomplished by establishing the desired number of trees or basal area for each diameter class.

When used with flexibility, the quotient q between number of trees in successive diameter classes is a widely accepted means of calculating diameter distributions in uneven-aged stands (Meyer 1952). Values of q ranging between 1.3 and 2.0 (for 2-inch diameter classes) have been recommended for various situations. The lower the q, the smaller is the difference in number of trees between diameter classes. Stands maintained at a small q have a higher proportion of available growing stock in larger trees, for any residual stocking level, but may require periodic removal of the largest number of small trees in the diameter class when unregulated growing stock crosses the threshold into the proportion of the stand to be regulated (Alexander 1986, Alexander and Edminster 1977b).

Consider, for example, differences in the number of small and large trees maintained at a q level of 1.1, 1.3, and 1.5 in stands with the same residual basal area (80 square feet) (table 1). At all stocking levels considered appropriate for future management goals, many small trees would have to be cut under lower q levels at the threshold diameter class (in this example, the 4-inch class). Fewer larger trees would be retained under higher q levels.

Without experience, data, or good growth and yield information, the best estimate of numbers of trees to leave by diameter classes is to use the lowest q value that is reasonable, in terms of existing and future markets, stand conditions, and funds available for cultural work. Examination of plot data from a wide range of irregularly stocked old-growth ponderosa pine stands indicates that pretreatment distributions are likely to range between 1.2 and 1.5 for 2-inch classes. As a general recommendation, q levels between 1.2 and 1.4 appear to be reasonable initial goals for the first entry into unmanaged stands. For the more shade tolerant white spruce, q levels of 1.4 to 1.6 appear to be reasonable initial entry goals.

Table 1.—Residual stand structure for 80 square feet of basal area (BA) and maximum tree diameter of 16 inches d.b.h. for various q values.

	q= 1.1		q=1.3		q= 1.5	
Diameter class	No. trees	BA (ft^2)	No. trees	BA (ft^2)	No. trees	BA (ft^2)
4	26.92	2.35	51.73	4.52	83.94	7.33
6	24.49	4.81	39.73	7.80	55.94	10.98
8	22.21	7.75	30.63	10.69	37.29	13.02
10	20.23	11.03	23.56	12.85	24.91	13.58
12	18.40	14.45	18.10	14.22	16.58	13.02
14	16.73	17.88	13.92	14.88	11.06	11.82
16	15.21	21.24	10.71	14.95	7.37	10.29
Total	144.19	79.51	188.38	79.91	237.09	80.10

How to Determine Residual Stand Structure

Once goals for residual stocking, maximum tree diameter, and q levels have been selected, the specific structure for a stand can be calculated, provided that data are available to develop a stand table (Alexander and Edminster 1977b).

An existing old-growth ponderosa pine stand was selected to illustrate the procedure. The actual inventory data for the stand is shown in columns 1, 2, and 3 of table 2. A residual basal area of 80 square feet per acre in trees 4 inches d.b.h. and larger has been chosen. A maximum tree diameter of 16 inches d.b.h. was chosen, because it also appears to be a realistic goal to be attained in a reasonable period of time. Finally, a q of 1.3 was chosen, because it approximates the q in the natural stand and does not require removal of many small trees. A lower q may be feasible; but it would require heavy cutting in lower diameter classes.

To determine the residual stand goal, the value of the residual density parameter k corresponding to a basal area of 80 square feet must be calculated. Values needed for this computation with a q of 1.3 are given in column 4 of table 3. The value of k is computed as

$$k = \frac{80.0}{0.62428 - 0.01678} = 131.6872$$

where 80.0 is the desired basal area per acre, 0.62428 is the table value for the desired maximum tree diameter class of 16 inches, and 0.01678 is the table value for the 2-inch class. Note that the value for the 2-inch class is subtracted from the 16-inch class value, because trees smaller than the 4-inch class are not considered in the management guidelines. Desired residual number of trees in each diameter class (column 4 of table 2) can be directly calculated by multiplying the proper diameter class values given in column 4 of table 4 by the value of k. The desired residual basal area in each diameter class (column 5 of table 2) can be calculated by multiplying the residual number of trees in each diameter class by the tree basal area.

Comparing actual and desired diameter distributions shows where deficits and surpluses occur (fig. 19). To bring this stand under management, the number of trees should be allowed to increase in the diameter classes that are below the idealized stocking curve, with cutting limited to those diameter classes with surplus trees. As a guide, enough trees should be left above the curve in surplus diameter classes to balance the deficit in trees in diameter classes below the curve. However, in this example that was not done, because a deficit occurred only in the 10-inch d.b.h. class. Cutting to the recommended residual stand in the 8-inch d.b.h. class will provide enough trees to meet the stocking goals in the 10-inch d.b.h. class at the time of the next entry. All surplus trees were cut in the other diameter classes. The final stand structure is shown in fig. 20 and columns 6 and 7 of table 2. Columns 8 and 9 show the trees and basal area removed. Note that the ultimate goal of 80 square feet of residual basal area was not attained in the first entry, because no surplus trees were left in the 8-inch d.b.h. class to make up for the deficit in the 10-inch d.b.h. class.

How to Handle Small Trees

The threshold diameter class also must be determined. Calculations often are made down to the 4-inch diameter class by 2-inch classes, because there are often small trees below minimum merchantable diameter, especially in mixed stands. They compete with larger stems for growing space. More important, these trees provide ingrowth into merchantable size classes needed to practice selection silviculture.

Although small trees should not be ignored in inventory and record keeping, it may be neither desirable nor possible to regulate their numbers. In ponderosa pine forests in the Black Hills, minimum merchantable diameter usually varies from 5 to 8 inches. Regulation of the number of trees below this size requires an investment in silvicultural work that may not be recaptured under prevailing market conditions. However, if trees below minimum merchantable size are left unregulated, cutting always must be heavy in the threshold diameter class to bring ingrowth trees down to the desired number. It also means that more growing space is required for

Table 2.—Actual stand conditions and management goals for ponderosa pine stands. All data are on a per acre basis—stand goals q = 1.3, residual basal area 80 square feet, maximum tree diameter 16 inches d.b.h.

Diameter class	Actual stand		Residual stand		Final stand		Cut	
	Trees	BA	Trees	BA	Trees	BA	Trees	BA
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
4	58	5.06	51.73	4.52	52	4.54	6	0.52
6	41	8.05	39.73	7.80	40	7.85	1	0.20
8	42	14.66	30.63	10.69	31	10.82	11	3.84
10	19	10.36	23.56	12.85	19	10.36	0	0
12	18	14.13	18.10	14.22	18	14.11	0	0
14	19	20.31	13.92	14.88	14	14.79	5	5.43
16	14	19.55	10.71	14.95	11	15.34	3	4.21
18	1	1.77					1	1.77
20	1	2.18					1	2.18
22	2	5.28					2	5.28
Total	215	101.35	188.38	79.91	185	78.02	30	23.43

Table 3.—Values needed to compute k for different q ratios and diameter ranges using basal area as the density measure (Alexander and Edminster 1977b).

2-inch diameter classes	q ratio				
	1.1	1.2	1.3	1.4	1.5
(1)	(2)	(3)	(4)	(5)	(6)
2	0.01983	0.01818	0.01678	0.01558	0.01454
4	.09196	.07878	.06842	.06011	.05333
6	.23948	.19241	.15779	.13166	.11151
8	.47790	.36075	.28001	.22253	.18046
10	.81656	.57994	.42691	.32394	.25228
12	1.25990	.84297	.58963	.42825	.32124
14	1.80848	1.14132	.75999	.52966	.38380
16	2.45985	1.46605	.93116	.62428	.43828
18	3.20930	1.80854	1.09780	.70981	.48425
20	4.05043	2.16089	1.25606	.78523	.52209
22	4.97568	2.51618	1.40336	.85042	.55251
24	5.97669	2.86853	1.53820	.90583	.57682

Table 4.—Values needed to compute desired number of residual trees for different q ratios (Alexander and Edminster 1977b).

2-inch diameter classes	q ratio				
	1.1	1.2	1.3	1.4	1.5
D_1 (1)	(2)	(3)	(4)	(5)	(6)
2	0.909091	0.833333	0.769231	0.714286	0.666667
4	.826446	.694444	.591716	.510204	.444444
6	.751315	.578704	.455166	.364431	.296296
8	.683013	.482253	.350128	.260308	.197531
10	.620921	.401878	.269329	.185934	.131687
12	.564474	.334898	.207176	.132810	.087791
14	.513158	.279082	.159366	.094865	.058528
16	.466507	.232568	.122589	.067760	.039018
18	.424098	.193807	.094300	.048400	.026012
20	.385543	.161506	.072538	.034572	.017342
22	.350494	.134588	.055799	.024694	.011561
24	.318631	.112157	.042922	.017639	.007707

small trees than called for by the idealized stand structure. Moreover, the higher the threshold diameter class, the greater is the proportion of the stand that is unregulated. More growing space is occupied by trees of low value that will be cut as soon as they cross the threshold diameter (Alexander 1986, Alexander and Edminster 1977b).

Marking Trees

After residual stocking goals have been calculated and a decision has been made on how to handle small trees, the stand must be marked. Marking is difficult, because the marker must designate cut or leave trees, usually with one pass through the stand, based on limited inventory data. At the same time, the marker must apply good silviculture and be aware of economic limitations. As a general rule, good silvicultural prescriptions are more important than strict adherence to structural goals, especially in unregulated stands being cut for the first time. However, marking without a structural goal—or prescribing structural goals that cannot be attained or applied—defeats the objective of regulation.

Because marking for individual-tree selection cutting is more complex than for other systems, some formal control procedure is necessary. Often only an estimate of the initial desired residual diameter distribution is needed. With these estimates, basal areas and number of trees to be removed per acre by diameter classes can be determined. Control is maintained by a process of successive checks of residual versus the goal. For example, the markers systematically should make prism estimates of the residual stand after marking, recording trees by 2- or 4-inch classes on a standard cumulative tally sheet. Periodically, they should convert the prism tally to trees per acre and compare their average prism estimate to the structural goal. Markers then must adjust to any serious deviation from the structural goal, such as too heavy marking in some diameter classes and too light in others. Their next check will determine if progress is being made or if further changes are needed. By this process, the average residual stand should come fairly close to the structural goal (Alexander and Edminster 1977b).

Marking under group selection cutting is less complex than under individual-tree selection, but control over the diameter distribution also is necessary. The objective is to create a series of openings over time and space with each opening containing a given diameter class.

It is not likely that unregulated stands will be brought under management with one entry or even a series of entries. It is more likely that limitations imposed by economics, stand conditions, and mountain pine beetle susceptibility will result in either over- or undercutting, at least in the first entry.

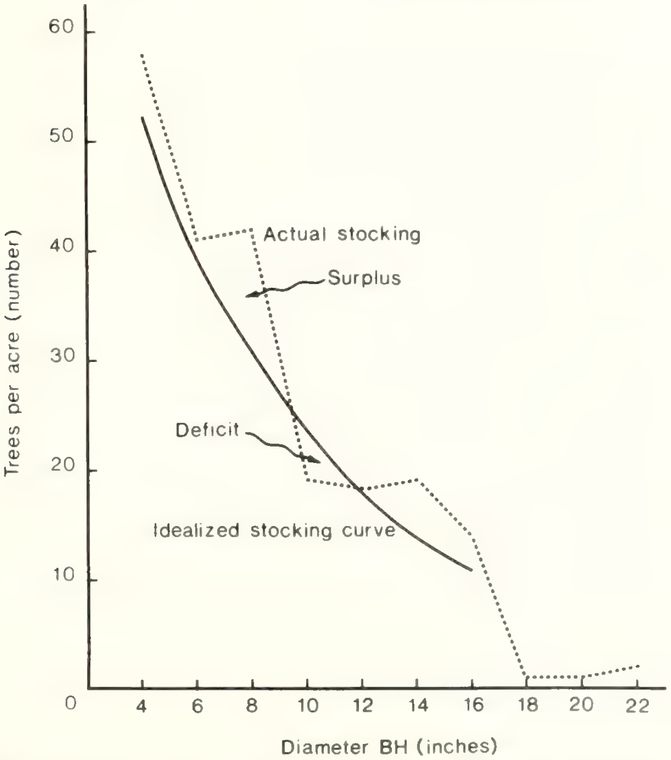

Figure 19.—Actual stocking curve from Black Hills data and the idealized stocking curve based on stand structure goals.

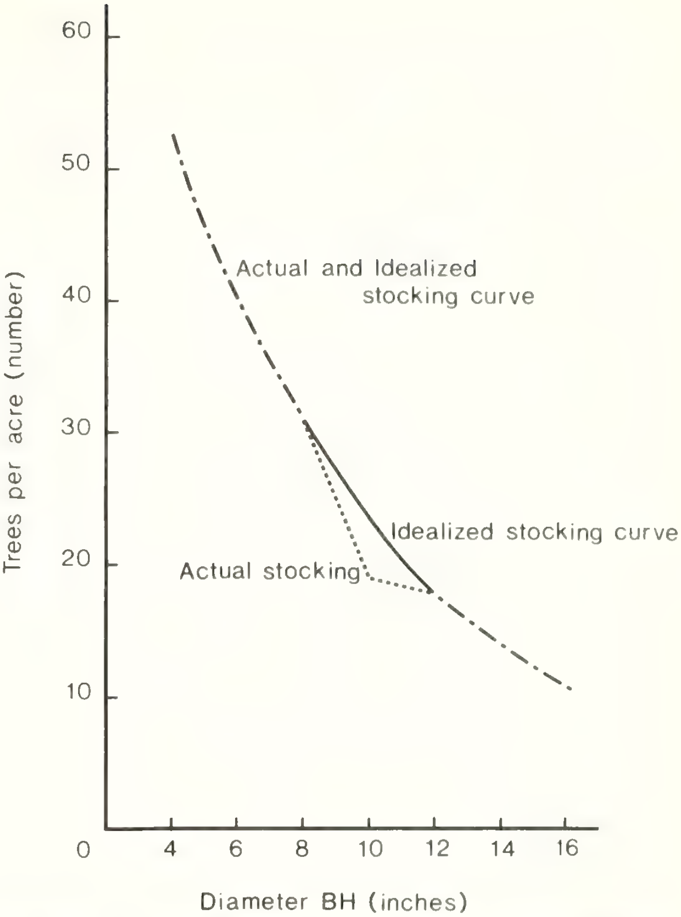

Figure 20.—Actual and recommended stocking curves based on stand structure goals and actual stand structure.

Recommendations for Selection Cutting

These are based on experience and mountain pine beetle susceptibility. Selection cutting methods are appropriate for multistoried pure or mixed conifer stands with irregular or uneven-aged stand structure. Individual-tree selection should be confined to mixed conifer stands with uniform spacing. Group selection can be used in stands with either clumpy, groupy, or patchy spacing, or uniform spacing. Selection cutting methods are not appropriate in stands sustaining a mountain pine beetle attack or in stands where enough beetles are present within the stand or adjacent stands to make successful attacks.

Stand Structure Goals, Cutting Treatments, and Reentry Schedules

While it is desirable to reach the residual stocking goal at the time of the first entry, not more than 50% to 60% of the stand basal area should be removed with individual-tree selection, and the cut should be distributed over the entire area. With group selection, the objective is to create groups of trees distributed over the area, with approximately the same number of groups in each 2- or 4-inch diameter class. Therefore, the amount of area cut at each entry should be proportional to the number of diameter classes. If the stand is groupy, clumpy, or patchy, the size of opening with group selection should be determined by the size of the group, clump, or patch. If the stand is uniformly spaced, the size of the opening should not exceed two to three times tree height. Keep the openings small.

Maximum tree diameter should not exceed that attained in the unmanaged stand. The diameter distribution should be set at a "q" value that most closely approximates the natural "q" value of the stand. However, remember that low q values require cutting more trees at the threshold diameter class, and high q values retain few larger trees. The threshold value should be set at the smallest diameter class practical. All trees below the threshold diameter class are unregulated. Some diameter classes will have a surplus of trees, and some will have a deficit. Surpluses and deficits must be balanced to attain the residual basal area. Subsequent entries should be made at 10- to 30-year intervals. While it would be desirable to enter the stand at 10-year intervals, it is not likely that growth rates initially will permit such frequent entries. The required number of trees in some diameter classes will not be available; therefore, volumes available for cutting may not warrant a 10-year reentry until a controlled diameter distribution is attained.

Protecting the Residual Stand

Protection of the residual stand is critical with individual-tree selection cutting because of frequent entries into the stand once a controlled diameter distribution is attained. Damage can result from felling, skidding, and slash disposal.

Felling damage can be reduced by using group selection and dropping trees in the openings or marking a small clump of trees where felling one large tree will damage several adjacent trees. Procedures outlined for protecting the residual and disposing of slash for shelterwood cutting should be followed here.

MANAGED STANDS— IMMATURE SINGLE-STORIED PONDEROSA PINE

Estimates of Growth Under Intensive Management

About one-half of the commercial ponderosa pine forest land in the Black Hills are occupied by single-storied, second-growth sapling, poletimber and immature sawlog stands. Extremely high densities are common in these naturally regenerated stands. Thinning is needed to reduce stand density early in the life of the stand. Intensive management of these forests provides many opportunities for increasing usable wood production; but estimates of future stand development under various thinning regimes are needed.

Information available on the growth of ponderosa pine from sapling stage to final harvest, under even-aged management, with a shelterwood cutting alternative, is provided by field and computer simulation procedures developed by Myers (1971) and refined by Edminster (1978). The procedures were developed from field data on past growth related to stand density, age, and site quality. Data were obtained from a large number of both permanent and temporary plots established in thinned and natural stands throughout the Black Hills.

Yield simulations discussed in the following paragraphs were made to the same hypothetical initial stand conditions for all growth parameters.

1. Average age at first GSL thinning is 30 years.
2. Average stand diameter is 4.5 inches d.b.h.[4]
3. Stand density is 1,000 tree per acre.
4. Site index is 50-, 60-, 70-, and 80-foot classes, at base age 100 years (Meyer 1961).
5. Projections were made for 50 years (stand age 80 years) and 90 years (stand age 120 years).
6. Thinnings from below were made every 20 and 30 years to growing stock levels (GSL) of 40, 60, 80, 100, 120, 140, and 160, with initial and subsequent entries made to the same growing stock level.
7. A two-cut shelterwood option was used. The seed cut was made 20 years before the final cut and retained 50% of the subsequent GSL.
8. Minimum size for inclusion in board-foot volume determination was 10 inches d.b.h. to an 8-inch top. Volumes were determined from tables prepared by Myers (1964).[5]
9. All entries were made as scheduled.

Diameter Growth

Periodic mean annual diameter growth of Black Hills ponderosa pine is related to stand density and site quality but is affected little by the cutting cycles tested. Cutting cycles do influence average stand diameter, however, because thinning from below increases average diameter at each entry. Actual basal area in a stand with an average diameter of less than 10 inches d.b.h. continues to increase, because periodic thinning does not reduce basal area to a fixed (GSL) amount until an average stand diameter of 10 inches d.b.h. is reached. Consequently, the rate of diameter growth for a given GSL is not constant over time and essentially is a negative exponential function of basal area per acre in the program. In contrast, periodic diameter growth is a linear function of site index, so that differences in diameter growth resulting from site quality are constant throughout the range of GSLs and rotations examined.

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[4] *Average diameter is the diameter of the tree of average basal area; it is not the average of all the tree diameters.*

[5] *Utilization standards in the Black Hills for board-foot volume determination are changing to 8 inches d.b.h. to a 6-inch top d.i.b. Estimates of board-foot volume growth and production in this paper may be slightly lower than actual board-foot volumes because of the change in utilization standards.*

Growth rates and changes in diameter resulting from thinning frequency were examined to determine average size of trees relative to rotation age. With a 20-year cutting cycle, for example, trees reach average stand diameters of 10.2 to 18.3 inches d.b.h. after 80 years, and 12.6 to 26.9 inches d.b.h. after 120 years for the range of GSLs and site indexes tested (table 5). On an average site (index 70), with a 20-year cutting cycle, mean stand diameters reached 10 inches d.b.h. at about 50 to 90 years of age for the range of GSLs 40 to 160 (fig. 21) (Alexander and Edminster 1981).

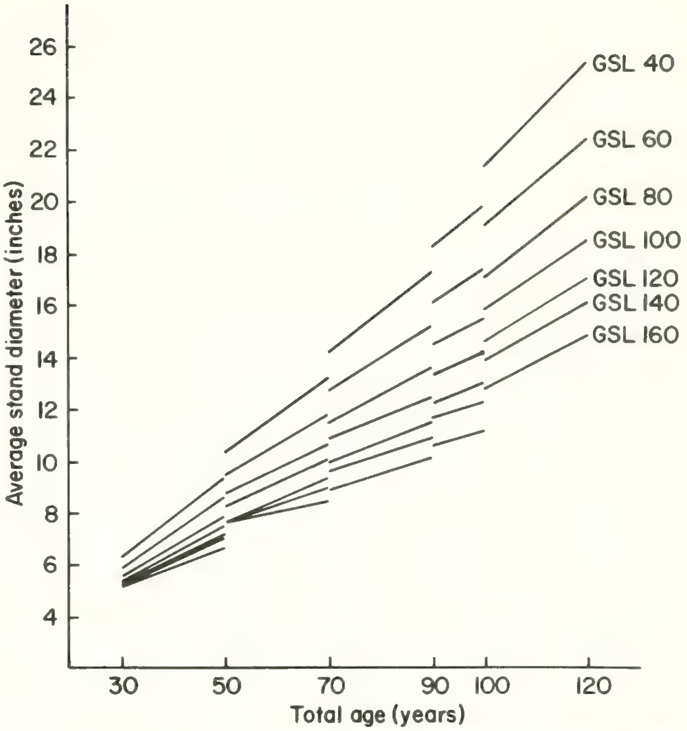

Figure 21.—Estimated average stand diameter of Black Hills ponderosa pine in relation to age and GSL on site index 70 lands, with a 20-year thinning interval.

Height Growth

Periodic mean annual height growth of ponderosa pine increases with site index and decreases with age, but is unaffected by GSLs, cutting methods, or the cutting cycles examined. However, because fewer and, therefore, taller trees are left after each thinning from below, the mean height of the dominant and codominant trees is increased

Table 5.—Estimated average diameter (inches) and number of trees per acre of Black Hills ponderosa pine at final harvest in relation to growing stock level, rotation age, cutting cycle, and site index.

		Growing stock level													
		40		60		80		100		120		140		160	
Rotation age	Cutting cycle	No. of trees	Dia.	No. of trees	Dia.	No. of trees	Dia.	No. of trees	Dia.	No. of trees	Dia.	No. of trees	Dia.	No. of trees	Dia.
								Site index 50							
80	20	22	16.5	39	14.8	64	13.3	92	12.3	119	11.5	153	10.8	189	10.2
120		9	23.7	18	20.6	29	18.5	46	16.4	63	15.3	89	13.9	123	12.6
80	30	24	15.9	45	14.1	72	12.7	101	11.7	131	11.0	165	10.4	202	9.8
120		10	22.9	20	19.6	33	17.6	50	15.9	67	14.9	94	13.6	128	12.4
								Site index 60							
80	20	21	17.0	38	15.3	60	13.9	83	13.0	111	12.1	145	11.3	180	10.7
120		9	24.4	17	21.5	27	19.4	40	17.6	56	16.3	77	15.0	105	13.7
80	30	23	16.4	42	14.6	67	13.2	92	12.4	124	11.5	155	10.9	192	10.3
120		10	23.5	18	20.7	30	18.5	45	16.7	62	15.6	82	14.6	109	13.5
								Site index 70							
80	20	20	17.5	36	15.8	55	14.5	80	13.3	106	12.6	132	12.0	168	11.2
120		8	25.4	15	22.5	25	20.2	37	18.5	52	17.1	66	16.2	90	14.9
80	30	21	17.1	39	15.2	63	13.8	90	12.7	120	11.9	147	11.4	183	10.9
120		9	24.8	17	21.7	28	19.2	41	17.6	56	16.5	74	15.5	99	14.3
								Site index 80							
80	20	18	18.3	34	16.4	53	15.0	77	13.7	100	13.1	130	12.3	154	11.9
120		7	26.9	14	23.5	22	21.4	34	19.4	46	18.2	62	16.9	79	15.9
80	30	20	17.7	37	15.8	61	14.1	85	13.2	110	12.6	142	11.8	174	11.2
120		8	25.8	15	22.7	25	20.4	38	18.5	50	17.5	68	16.2	87	15.3

slightly at each entry. The increase is positively correlated with thinning frequency and negatively correlated with GSL (Alexander and Edminster 1981).

Basal Area Growth

Periodic mean annual basal area increment is related to growing stock level, site quality, frequency of thinning, and rotation age. Because actual basal area continues to increase in a stand until average stand diameter reaches 10 inches d.b.h. and thinning reduces basal area to a fixed amount (GSL), the rate of basal area growth for a given GSL is not constant over time. Periodic basal area increment increases as growing stock level increases from 40 to 140, but the rate of increase diminishes as stand density increases. At GSLs above 140, basal area increment declines on all sites. Periodic mean basal area growth also increases as site index increases. Moreover, the differences in basal area growth between site classes become progressively greater as GSL increases. Periodic mean basal area increment is greater with a 30-year cutting cycle than with a 20-year entry at all rotations examined for GSLs 40 to 140 (Alexander and Edminster 1981).

Total Cubic-Foot Volume Increment

Cubic-foot volume production is related to stand density, site quality, rotation age, and frequency of thinning (table 6). Although mean annual cubic volume increment increases as growing stock level and site index increases, the rate of increase diminishes as GSL increases, while the differences in growth between site classes become greater (fig. 22) (table 7). Cubic volume increment for both rotations examined apparently will continue to increase at GSLs above 160 on site index 70 and 80 lands, but level off or decline on site index 50 and 60 lands at GSLs greater than 160. Mean annual cubic volume increment generally is greater with a 120-year rotation and a 30-year cutting cycle for all GSLs and site indexes examined (Alexander and Edminster 1981).

Board-Foot Volume Increment

Board-foot volume production is related to all stand parameters evaluated (table 8). Mean annual sawtimber volume growth increases on site index 70 and 80 lands as stand density increases from GSL 40 to 140. Above GSL 140, growth begins to level off. On site index 50 and 60 lands, growth generally levels off or declines at GSLs above 120 (fig. 23) (table 9).

Board-foot volume growth increases with site quality, and the differences in growth between site classes become greater as GSL increases. Throughout the range of GSLs tested, average annual board-foot increment per acre always is greater for all site classes on a 120-year rotation (fig. 24). There are no practical differences in board-foot volume growth between 20- and 30-year cutting cycles for the range of site indexes and GSLs tested (fig. 25) (table 9) (Alexander and Edminster 1981).

Table 6.—Estimated total cubic-foot volume production per acre of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle (in years), and site index.

Rotation age	Cutting cycle	Growing stock level						
		40	60	80	100	120	140	160
------ years ------		------------------- thousand cubic feet -------------------						
		Site index 50						
80	20	1.91	2.24	2.55	2.80	2.96	3.04	3.12
120		2.95	3.67	4.20	4.56	4.82	4.94	5.04
80	30	2.04	2.37	2.63	2.80	2.96	3.10	3.19
120		3.10	3.80	4.33	4.66	4.91	5.02	5.10
		Site index 60						
80	20	2.39	2.90	3.32	3.61	3.83	3.97	4.06
120		3.71	4.62	5.30	5.88	6.24	6.48	6.67
80	30	2.56	3.02	3.38	3.66	3.90	4.12	4.20
120		3.90	4.81	5.56	6.12	6.50	6.82	6.98
		Site index 70						
80	20	2.94	3.50	4.02	4.44	4.78	5.01	5.13
120		4.48	5.62	6.48	7.19	7.75	8.22	8.46
80	30	3.12	3.72	4.19	4.55	4.81	5.06	5.20
120		4.73	5.90	6.84	7.56	8.16	8.53	8.84
		Site index 80						
80	20	3.50	4.29	4.88	5.32	5.68	5.96	6.16
120		5.26	6.70	7.85	8.78	9.54	9.97	10.26
80	30	3.76	4.42	5.01	5.49	5.82	6.03	6.20
120		5.63	7.04	8.18	9.12	9.86	10.43	10.70

Table 7.—Estimated mean annual total cubic-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index.

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years	years	cubic feet						
					Site index 50			
80	20	23.9	28.0	31.9	35.0	37.0	38.0	39.0
120		24.6	30.6	35.0	38.0	40.2	41.2	42.0
80	30	25.5	29.6	32.9	35.0	37.0	38.8	39.9
120		25.8	31.7	36.1	38.8	40.9	41.8	42.5
					Site index 60			
80	20	29.9	36.2	41.5	45.1	47.9	49.6	50.9
120		30.9	38.5	44.2	49.0	52.0	54.0	55.6
80	30	32.0	37.8	42.2	45.8	48.8	51.3	52.5
120		32.5	40.1	46.3	51.0	54.2	56.8	58.2
					Site index 70			
80	20	36.8	43.8	50.2	55.5	59.8	62.6	64.1
120		37.3	46.8	54.0	59.9	64.6	68.5	70.5
80	30	39.0	46.5	52.4	56.9	60.1	63.2	65.0
120		39.4	49.2	57.0	63.0	68.0	71.1	73.7
					Site index 80			
80	20	43.8	53.6	61.0	66.5	71.0	74.5	77.0
120		43.8	55.8	65.4	73.2	79.5	83.1	85.5
80	30	47.0	55.3	62.6	68.6	72.8	75.4	77.5
120		46.9	58.7	68.2	76.0	82.2	86.9	89.2

Table 8.—Estimated total board-foot volume production per acre of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index (trees 10 inches d.b.h. and larger to an 8-inch top).

Rotation age	Cutting cycle	Growing stock level 40	60	80	100	120	140	160
years	years	thousand board feet						
					Site index 50			
80	20	4.40	4.88	5.28	5.52	5.60	5.36	4.96
120		11.04	12.96	14.28	15.12	15.36	14.88	13.80
80	30	4.32	4.88	5.04	5.20	5.04	4.72	4.16
120		11.04	13.20	14.28	14.88	15.00	14.04	12.60
					Site index 60			
80	20	5.68	6.40	7.12	7.68	7.84	7.84	7.52
120		13.92	16.80	18.84	20.16	21.24	21.36	20.64
80	30	5.92	6.40	6.72	6.96	7.04	6.96	6.72
120		14.28	16.92	18.84	20.16	20.88	20.64	19.92
					Site index 70			
80	20	7.20	8.08	8.96	9.76	10.40	10.64	10.64
120		16.80	21.48	24.36	26.16	27.60	28.08	28.20
80	30	7.68	8.48	8.96	9.28	9.60	9.76	9.76
120		18.12	21.84	24.60	26.76	27.84	28.20	28.32
					Site index 80			
80	20	8.88	10.24	11.36	12.32	13.20	13.76	14.08
120		20.64	26.04	29.64	32.16	34.20	35.64	35.88
80	30	9.76	10.88	11.60	12.16	12.64	12.80	12.96
120		22.32	26.64	29.88	32.52	34.32	35.64	36.00

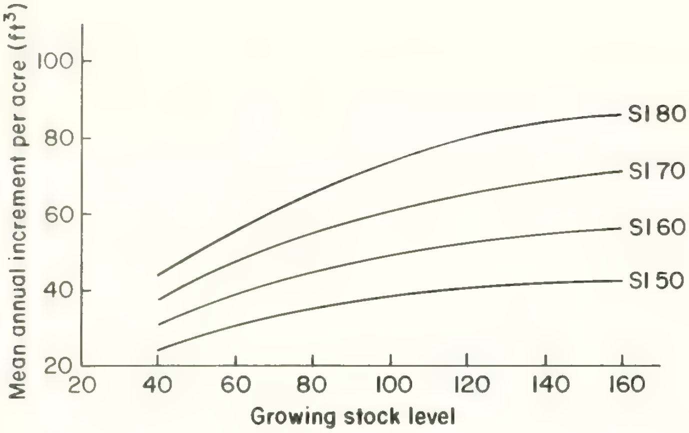

Figure 22.—Estimated mean annual total cubic-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level for a 120-year rotation, with a 20-year thinning interval (Alexander and Edminster 1981).

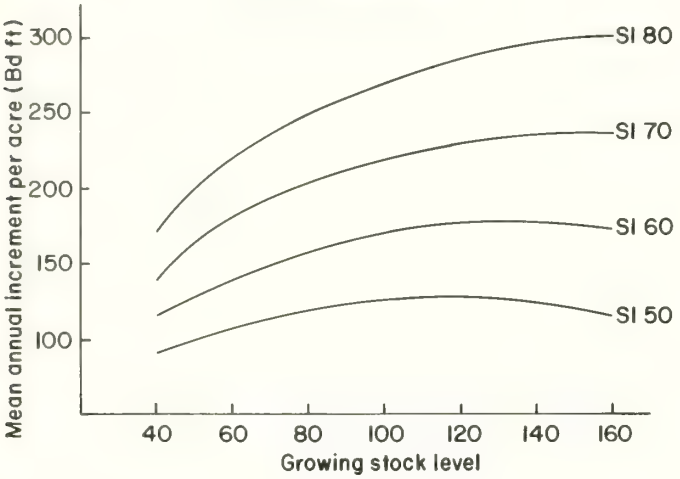

Figure 23.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level for a 120-year rotation, with a 20-year thinning interval (Alexander and Edminster 1981).

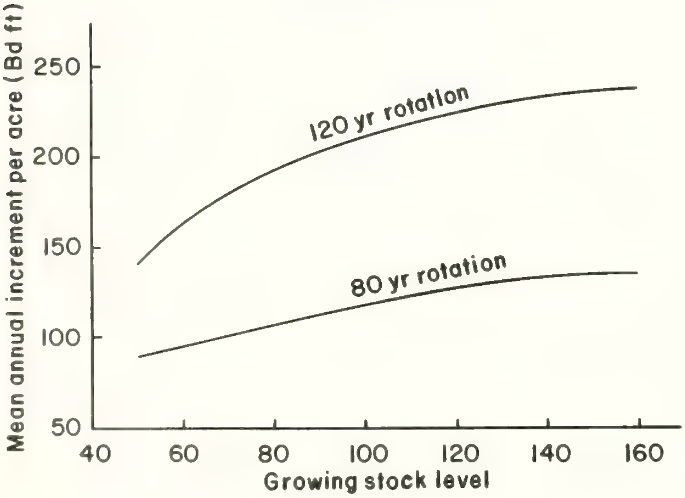

Figure 24.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine on site index 70 lands, with a 20-year thinning interval in relation to growing stock level and rotation age (Alexander and Edminster 1981).

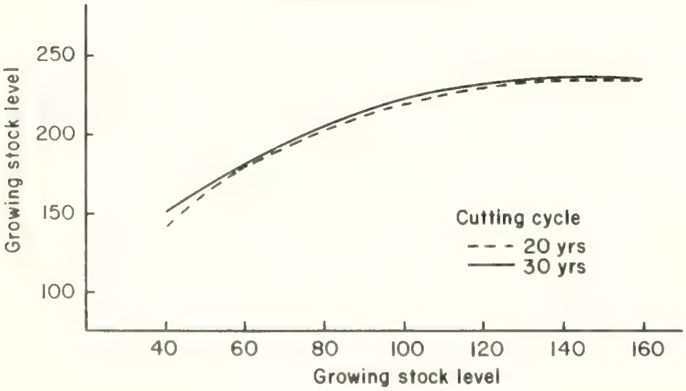

Figure 25.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine on site index 70 lands in relation to growing stock level and thinning interval (Alexander and Edminster 1981).

Table 9.—Estimated mean annual board-foot volume increment per acre of Black Hills ponderosa pine in relation to growing stock level, rotation age, cutting cycle, and site index (trees 10 inches d.b.h. and larger to an 8-inch top).

Rotation age	Cutting cycle	Growing stock level						
		40	60	80	100	120	140	160
years		*board feet*						
					Site index 50			
80	20	55	61	66	69	70	67	62
120		92	108	119	126	128	124	115
80	30	54	61	63	65	63	59	52
120		92	110	119	124	125	117	105
					Site index 60			
80	20	71	80	89	96	98	98	94
120		116	140	157	168	177	178	172
80	30	74	80	84	87	88	87	84
120		119	141	157	168	174	172	166
					Site index 70			
80	20	90	101	112	122	130	133	133
120		140	179	203	218	230	234	235
80	30	96	106	112	116	120	122	122
120		151	182	205	223	232	235	236
					Site index 80			
80	20	111	128	142	154	165	172	176
120		172	217	247	268	285	297	299
80	30	122	136	145	152	158	160	162
120		186	222	249	270	286	297	300

COST OF SALE ADMINISTRATION AND LOGGING

One of the most important factors affecting the administrative cost of selling timber is the number of entries needed for harvesting. Clearcutting and simulated shelterwood require only one entry. Seed-tree cutting requires one or two entries, depending upon whether the seed trees are harvested. Standard shelterwood requires two to three entries. Group shelterwood, individual-tree, and group selection require from three to six entries, depending upon cutting cycles. In managed stands, even-aged systems require a minimum of two additional entries for thinnings; but the number of entries under uneven-aged systems would not change.

Costs of sale layout, marking, and sale contract administration are lower for clearcutting, simulated and group shelterwood, and group selection (when groups are near the maximum size), and the final cut of a seed-tree and standard shelterwood than for individual-tree selection, the seed cut of a seed-tree, and the intermediate, preparatory, and seed cuts of standard shelterwood. Costs are reduced, because only cutting boundaries are marked, and no time is spent marking trees to cut or leave. Sale administration is easier, because there are no residual trees to protect and no opportunity to cut unmarked trees. However, reproduction must be protected at the time of final cut under seed-tree and any shelterwood system. Costs for selection methods are increased further, because good data and highly skilled individuals are required to recognize, mark, and protect trees that needed to be left to obtain the regulated distribution of diameter classes.

Timber harvesting usually requires road construction. Clearcutting is the most economical method, in terms of volume removed per unit of road, while individual-tree selection is the most expensive. Development of a transportation system to manage forests is a costly front-end investment that will require funding, in addition to the value of stumpage at the time of first entry. Once the transportation system has been constructed, road costs should be independent of cutting method.

In addition to producing maximum volume per acre in one operation, clearcutting and seed-tree cutting permit the greatest flexibility in selection of logging equipment and minimum concern for protection of residual trees. The first entry of a standard shelterwood is intermediate in volume production per acre, requires moderate concern for the residual stand, and places some constraints on selection of equipment. The final cut of a seed-tree, standard shelterwood, or simulated shelterwood has the advantages of clearcutting, except for the need to protect the new stand. Individual-tree selection requires maximum concern for the residual stand. Group selection and group shelterwood require slightly less if the size of the opening is near maximum. Under uneven-aged and group shelterwood cutting methods, volumes per entry are intermediate, size-class diversity of products harvested is maximum, and a choice of logging equipment is restricted to smaller or specialized machines.

MULTIPLE-USE SILVICULTURE

Potential Timber Yields

Natural Stands

Highest potential timber yields can be achieved under a clearcutting, seed-tree, or a two-cut shelterwood option, provided that the final harvest with a seed-tree or shelterwood is made within 5 years after regeneration is established. Comparable growth rates can be achieved with group shelterwood and group selection only if the openings are near the maximum size (2 acres). Total yields will be less under a three-cut shelterwood. Under simulated shelterwood, yield increases resulting from reduction in rotation length will be offset by the slower growth of the replacement stand. Yields will be considerably less under individual-tree and group selection in situations where very small openings are cut.

Managed Stands

The largest volume production per acre (about 36,000 fbm) is attained on site index 80 lands, at GSLs 140 to 160, on a 120-year rotation, with either a 20- or 30-year cutting cycle (table 8). These stands will contain between 60 and 90 trees per acre, with an average diameter of between 15 and 17 inches d.b.h. at rotation age (table 5).

Maximum volume production per acre on site index 70 lands (about 28,000 fbm) also is at GSLs 140 to 160; but GSL 120 is nearly as productive. Volume production declines substantially when GSL is reduced below 140 on site index 80 lands, and below 120 and site index 70 lands. The decline is greater with each successive reduction in GSL. On site index 50 and 60 lands, the largest volume production occurs at GSLs 120 to 140, respectively, on a 120-year rotation with a 20-year cutting cycle (table 8) (fig. 26).

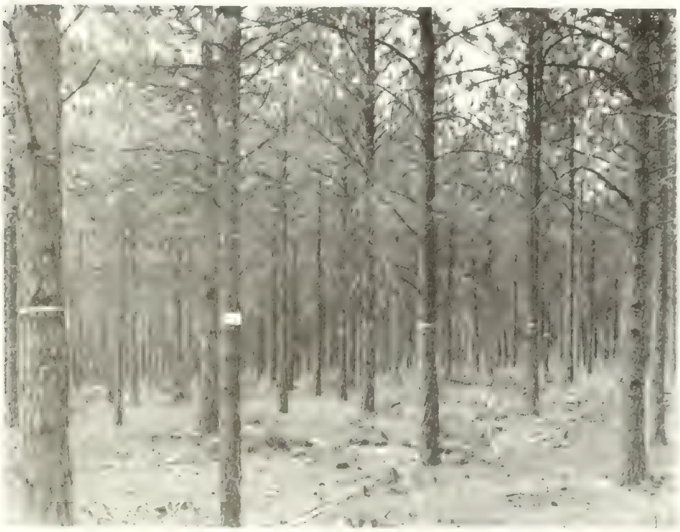

Figure 26.—Second-growth Black Hills ponderosa pine on an average site thinned to GSL 120. Stand now averages 6.2 inches d.b.h., was first thinned in 1963, and rethinned in 1973 (Alexander and Edminster 1981).

Table 8 also shows the amount of volume given up as GSL is reduced from the level of maximum production to 40 for all combinations of stand parameters examined. Moreover, it shows that more volume can be produced over the same time span with a 120-year rotation than with an 80-year rotation. For example, on site index 80 lands, at GSLs 140 to 160, average volume production per acre on two 120-year rotations or 240 years would be about 72,000 fbm, compared with about 40,000 fbm per acre on three 80-year rotations, also 240 years.

Whether the board-foot volume production potentials can be achieved largely depends on how much money can be invested in thinning. The assumption has been made that once a stand reaches a minimum size of 5 inches average d.b.h., intermediate thinnings will be made as scheduled. If economic, social, or political constraints (such as concern about below cost timber sales) limit managers to either one precommercial thinning or no precommercial thinning[6] in the life of the stand, their options are restricted severely. For example, with only one precommercial thinning on site index 50 lands, stand density must be reduced to GSLs 60 and the cutting cycle increased to 30 years (table 10). On site index 60 and 70 lands, a GSL of 100 can be maintained with a 30-year cutting cycle, and on site index 80 lands, a GSL of 120 can be maintained.

Thinnings to a constant GSL have been assumed. However, if only one precommercial thinning is possible, managers can increase their flexibility by changing GSLs with successive reentries. This especially is important where financial resources are limited. For example, on site index 70 lands, with a 30-year cutting cycle, stand density initially is reduced to GSL 100. At the time of the second thinning, GSL is increased to 120 and increased to GSL 140 with the third thinning. Volume production will be less than maximum but reasonably close to the volume available from a stand maintained at a constant GSL 140. Attempts to raise the GSL to 140 at the time of the second entry into the stand would result in a second precommercial thinning. By following this procedure, managers also could increase GSLs on site index 50 lands from 60 to 100 (Alexander and Edminster 1980).

The manager has another option if only one precommercial thinning is possible. The initial thinning can be made on schedule and the second entry delayed until the stand reaches minimum merchantable size. This will increase the thinning interval to 40 years or more, increase the length of rotation, and result in less than maximum volume production.

If economic conditions ever permit investment of funds in two precommercial thinnings, the manager has the opportunity to maximize timber production with a constant GSL that ranges from 100 on site index 50 lands to

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[6] *With no precommercial thinning, the manager must try to keep initial stocking as low as possible and still maintain site occupancy; wait until the stand reaches minimum merchantable size; and enter the stand and reduce stocking to GSL 40 to 60. At these stocking levels, regeneration will establish. It is not likely that another entry will be made until the final cut. Rotations and cutting cycles will be longer than desirable, and volume production will be significantly reduced. However, direct costs also will be reduced.*

140 on site index 80 lands with a 30-year thinning interval (table 10).

Managers also may elect to change GSLs with successive reentries, regardless of the number of precommercial thinnings that may be economically possible. With this procedure, the concern about retaining large numbers of trees early in the life of the stand and small numbers of trees later in the rotation can be avoided. For example, stand density can be reduced initially to GSLs 60 to 80 and successively increased to GSLs 100 to 140, depending upon site quality and cutting cycle. Volume production would be less than if density were maintained at a constant and higher initial GSL, however (Alexander and Edminster 1981).

The relationship between mountain pine beetle populations, individual ponderosa pine susceptibility, and stand density have not been determined where density has been controlled for the life of the stand. However, there is no research or experience to suggest that managed stands maintained at GSLs 100 to 140, which are below the densities of unmanaged stands with 150 to 260 square feet of basal area that are most often attacked, will be as susceptible to beetles (Sartwell and Stevens 1975).

Soil Water Resources

Water Yield

Black Hills ponderosa pine forest areas yield more water than southwestern or Front Range ponderosa pine forest areas (Gary 1975, Leaf 1975, Orr 1975). They yield less water than the subalpine forest areas in central Rocky Mountains with about the same amount of precipitation, because the source of runoff and the distribution pattern is different, and evapotranspiration demands of vegetation are higher during a longer and warmer growing season. About 25% of the precipitation is available for streamflow in the Black Hills. In the northern Black Hills where precipitation is heaviest (average 28 inches), water yields from untreated pine forests on the Sturgis watersheds averaged about 7 inches from 1964 to 1969 (Orr and VanderHeide 1973). More than 90% of the annual runoff was produced by 52% of the annual precipitation, which fell during the period of April to June. Winter snowfall is important to the recharge of soil moisture and to early runoff during the spring melt period; but it contributes little to total streamflow. Anderson (1980) reported average streamflow increases of 1.93 inches for 8 years after a partial cut on 50% of the Sturgis watershed. Increases were greatest during the wet years.

The potential for increasing streamflow in the Black Hills should be greater than the slightly more than 1 inch available from southwestern and Front Range ponderosa pine forests. The most effective pattern of timber harvest for increasing water yields is to clearcut some portion of first order basins and interbasin areas in small irregular patches, provided that conveyance and other losses are minimal (Leaf 1975, Orr 1975).

The increase in streamflow resulting from clearcutting is largely caused by reduced interception and evapotranspiration. Redistribution of snow is less important in the Black Hills than in central Rocky Mountain subalpine forests (Leaf 1975). Not only is evapotranspiration and interception reduced by removing trees in cleared patches, but soil moisture is recharged fully earlier in the growing season, resulting in more runoff and a longer runoff period than in uncut or partially cut stands (Orr 1968, 1975). The increase in water available for streamflow diminishes as understory vegetation becomes established. However, it will not return to pretreatment levels until the site is fully occupied by a new stand of trees.

Seed-tree, group shelterwood, and group selection cutting can be nearly as favorable for increasing streamflow as patch clearcutting if group openings are near the maximum size of 2 acres. In the low precipitation-high energy environment of the Black Hills, partial cutting treatments, such as individual-tree selection and shelterwood, are not as efficient in increasing water yields as they are in higher elevation spruce-fir forests in the central Rocky Mountains.

Thinning second-growth ponderosa pine also reduces soil moisture deficits, resulting in a greater potential for increased streamflow. But reducing basal area to 80 square feet, a common practice in the Black Hills, will

Table 10.—Number of precommercial thinnings of Black Hills ponderosa pine in relation to growing stock level, cutting cycle, and site index.

Cutting cycle	Site index	Growing stock level 40	60	80	100	120	140	160
years								
20	50	2	2	2	2	3	3	4
	60	2	2	2	2	3	3	3
	70	1	2	2	2	2	3	3
	80	1	2	2	2	2	3	3
30	50	1	1	2	2	2	3	3
	60	1	1	1	1	2	2	3
	70	1	1	1	1	2	2	2
	80	1	1	1	1	1	2	2

result in less water available for streamflow than at stocking levels less than 60 square feet basal area per acre.

Soil Erosion

Soil and site conditions are not the same in all Black Hills ponderosa pine forests; but many of them grow on either residual soils derived from granitic schists or alluvium soils derived from granitic rock that are medium to fine textured, easily compacted, and therefore, subject to higher volumes and more rapid runoff for a given rainfall. These soils generally are considered to be naturally erosive. When protective plant cover is removed and soils are disturbed by roadbuilding, logging, and fire, natural erosion processes are accelerated (Orr 1975). Because roads are considered the largest single cause of erosion and sedimentation in the Black Hills, careful location, construction, and maintenance of skid and haul roads is required. If this is done, roadbuilding associated with any cutting method should not cause a lasting increase in erosion.

Nutrient Loss and Stream Water Temperature Changes

Removal of logs in timber harvest represents a small and temporary net loss of nutrients, because only a minor proportion of the nutrients taken up by a tree is stored in the bole. Cutting that removes all, or most all, trees results in a greater immediate loss than partial cutting; but over a rotation, the losses would balance out because of more frequent cuts under the partial cutting methods. Furthermore, nutrients lost after cutting all, or most all, trees should be replaced in 10 to 20 years through natural cycling as regeneration becomes established. Increases in stream temperature can be avoided, even with clearcutting, by retaining a border of trees along stream channels.

Wildlife and Range Resources

Game Habitat

Mature ponderosa pine stands provide habitat for a variety of game animals. Clearcutting in small (3- to 5-acre) openings, seed-tree cutting, group shelterwood, and group selection provide the largest increases in quantity and quality of forage for big game; but use can be limited unless adequate amounts of cover are available for hiding, resting, and ruminating.

Dispersed openings of 2 and 5 acres are used more by deer and elk than smaller or larger openings or uncut timber. Very small openings provide little diversity, and game animals often are attracted only to the edges around large openings. As trees grow to seedling and sapling size, forage production and understory cover in cleared areas diminishes; but overstory cover increases until it reaches maximum in mature stands.

Standard shelterwood cutting provides less forage for big game than cutting methods that create openings; the reduction is in proportion to the density of the overstory and length of time it is retained (Pase 1958). Shelterwood cutting also provides less cover than an uncut forest. Individual-tree selection provides forage and cover comparable to uncut forests, thereby maintaining one type of habitat at the expense of creating diversity.

Partial cutting methods, except for seed-tree, in stands with an oak or aspen component, or adjacent to oak or aspen stands, provide dens, roosts, and cover for game animals, such as turkey (*Meleagris gallopavo* Linnaeus) and fox squirrels (*Sciurus nigra* Linneaus). Conversely, cutting methods that remove all, or nearly all, of the trees on a large area are harmful to their habitat.

Nongame Habitat

Information is limited on the relationship of cutting methods in ponderosa pine forests in the Black Hills to specific nongame habitat requirements; but it is possible to estimate probable effects. Clearcutting, seed-tree cutting, group shelterwood, and group selection that create small, dispersed openings provide a wide range of habitats attractive to some birds and small mammals by increasing the amount of nontree vegetation—at least initially—and length of edge between dissimilar vegetation types.

Standard shelterwood cutting provides a variety of habitats attractive to species that forage in stands with widely spaced trees, but not those that require closed forests or fully open plant communities. Under this method, trees still are available for nesting, denning, and feeding until the final harvest, when consideration should be given to retaining some of the limby live trees and snags and live trees with cavities.

Harvesting old-growth timber can be detrimental to species that nest or den in snags and in cavities of live trees, feed largely on insects, and require solitary habitats normally associated with large areas of old-growth. Most nongame species have a minimum habitat size below which they cannot exist. Small patches of varying ages and structure and all-aged stands may reduce the number of species. Individual-tree selection provides the least horizontal diversity and favors species attracted to uncut forests or that require high vertical diversity. However, snags and live tree cavities can be retained under any silvicultural system.

The low-vigor, large-limbed, or dead trees used by wildlife would be prime choices for removal if special effort is not made to save them. So few trees per acre are involved in this type of habitat maintenance that their preservation has a negligible adverse effect on the appearance of the forest and other values. Regardless of the silvicultural methods applied, these trees should remain standing as long as they are useful to wildlife.

Livestock Grazing

Historically, Black Hills ponderosa pine and associated ranges have been important livestock producing areas.

Pine and rangeland types are a complex of plant communities. Their common characteristic is open grassland parks interspersed with forested areas. Natural forested areas may be open with extensive herbaceous understory vegetation or closed with little or no understory vegetation. Forage production and changes in species composition and palatability vary considerably, depending upon plant community and successional stage (Pase 1958). Forage production increases most when clearcutting, seed-tree cutting, group shelterwood, and group selection openings are cut in dense stands. The increase in forage production in these openings persists for 10 to 20 years before competition from tree reproduction begins to reduce understory vigor and composition. It can be maintained only by frequent intermediate cuttings to keep density low. Forage production after shelterwood and individual-tree selection cutting is in relation to the amount of overstory retained and time between entries in the stand (Pase 1958, Kranz and Linder 1973).

Because understory production is inversely related to overstory density, the following regression model developed by Pase (1958) was used to estimate potential production.

$$\text{Log } y = 3.22260 - 0.00936x$$

where

y = herbage production (pounds per acre)
x = basal area (square feet per acre)
Log = logarithm to base 10

Forage production is estimated to vary from about 1,700 pounds per acre on clearcut areas to as little as 20 pounds per acre under dense stands (200 or more square feet basal area per acre) (fig 27). With 80 square feet basal area, a common density for managed stand in the Black Hills, forage production is only about 300 pounds per acre. Forage production estimated by this equation is an average for the Black Hills; actual production will vary according to habitat type.

Severson and Boldt (1977) reported on the preliminary results of a study to measure overstory/understory production in sapling and pole-sized stands of Black Hills ponderosa pine that had been thinned to GSLs 0, 20, 60, and 100 in 1963, and again in 1973. Their preliminary findings indicated that forage production was greatest under stands where GSL was reduced to 0 or 20. The combined production of wood and forage was greatest at GSLs 60 to 100, but no estimates of combined production were made at higher GSLs. This study, however, reports the results of only one measurement of changes in understory production in relation to overstory density. Consequently, these data cannot be used reliably to quantify changes in forage production under Black Hills ponderosa pine for the range of GSLs, site indexes, cutting cycles, and rotation ages examined. However, some general conclusions can be drawn from the data provided by Pase (1958) and Severson and Boldt (1977). To increase herbage production to even moderate levels (400 to 500 pounds per acre, depending upon habitat type), the manager must be willing to reduce basal area stocking to less than 60 square feet per acre (fig. 28). Moreover, to maintain this forage production, additional cuts must be made in pole-sized or larger stands at intervals of at least every 20 years.

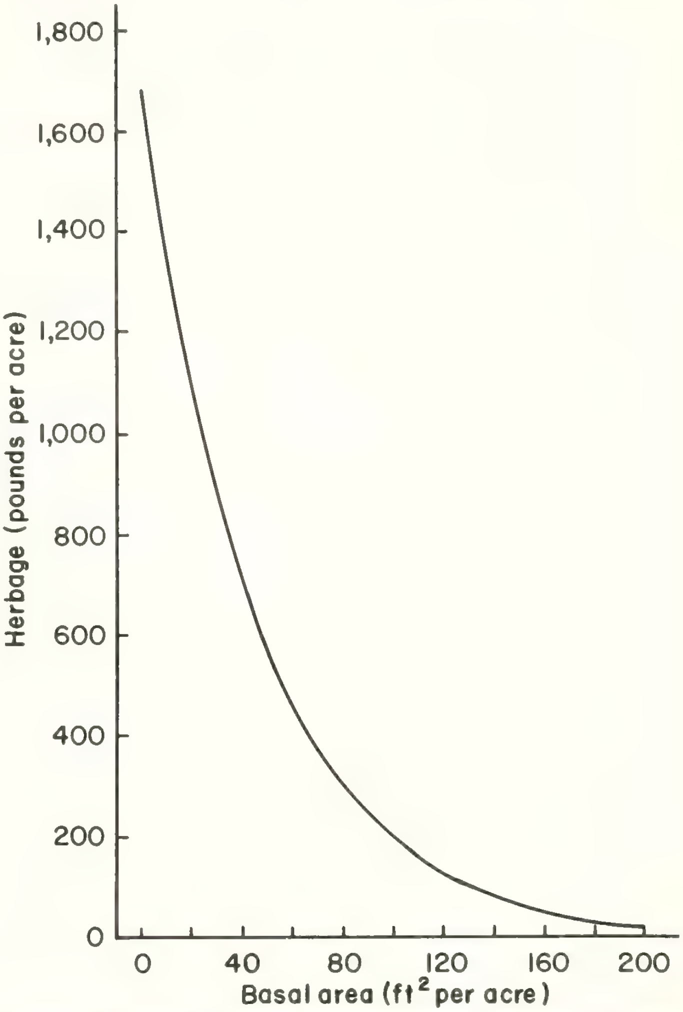

Figure 27.—Relation of herbage production to basal area of Black Hills ponderosa pine (Pase 1958).

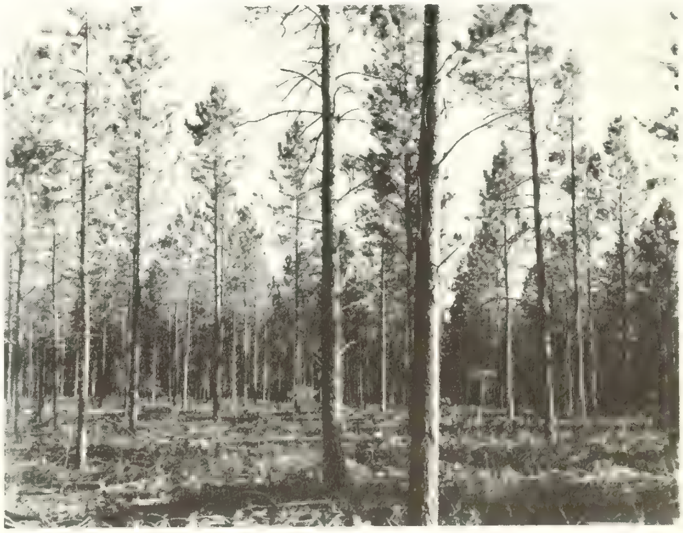

Figure 28.—Second-growth Black Hills ponderosa pine on an average site thinned to GSL 40. Stand now averages 7 inches d.b.h., was first thinned in 1963, and rethinned in 1973 (Alexander and Edminster 1981).

Recreation and Esthetics

Ponderosa pine forests in the Black Hills provide a variety of recreation opportunities. Users who hike, backpack, or view scenery generally are attracted to forests whose natural appearance is little altered by human activities (Calvin 1972). In contrast, hunters have best success where human activities are apparent—timber sales and other areas readily accessible by roads. Fishing is done mostly in accessible lakes, reservoirs, and streams. Generally, most camping opportunities are at both publicly and privately developed sites served by roads. Most scenery viewing is by automobile on developed roads. Finally, some forms of recreation, such as home development, require major modification of the natural forest landscape.

Clearcutting and seed-tree cutting have the greatest visual impacts, and individual-tree selection the least. However, variety typical of forests whose texture is broken by natural openings is preferred to the monotony of unbroken forest landscapes (Kaplan 1973).

To enhance amenity values, cutting openings (including seed-tree) to harvest timber and improve wildlife habitat should be a repetition of natural shapes visually tied together to create a balanced and unified pattern that will complement the landscape (Barnes 1971). This especially is important for openings in the middleground and background seen from a distance. Standard or simulated shelterwood or individual-tree selection can be used to retain a landscape in foregrounds.

Selection and shelterwood cutting methods usually are most appropriate in high-use recreation areas, travel influence zones, scenic view areas, and subdivision developments where permanent forest cover is desired. The most scenic stands tend to be open-grown stands of large yellow bark ponderosa pines that typically are managed for by reducing stand density to low levels and maintaining long rotations. In the Black Hills, careful cleanup of slash and other logging debris, and location of roads historically have retained esthetic values. Virtually every acre has been harvested or thinned at least twice in the past century. A full array of cutting methods have been used in even the most visible areas.

COMPARISON OF CUTTING METHODS

No silvicultural system or cutting method (including no cutting at all) meets all resource needs. Clearcutting, seed-tree cutting, group shelterwood, and group selection that cut small openings provides maximum yields of timber at less costs, promotes the largest increases in water production without serious reduction in quality, produces a diversity of food supply and cover favored by many wildlife species, and is necessary for the development of recreation sites and home subdivisions. Production and utilization of livestock forage may be less than in larger openings, however. Cutting openings can create adverse visual effects if no thought is given to the size and arrangement of the openings; but it also can be used to create landscape variety that will enhance amenity values.

Standard and simulated shelterwood cutting also provide maximum timber yields over the same time interval but at increased costs; they produce a wide range of wildlife habitats but with less forage than openings and less cover than uncut forests. Water yields may not be greatly increased over natural streamflow, however. Shelterwood cutting provides a partial retention of the forest landscape, particularly when the overstory is retained for a long time.

Individual-tree selection cutting is not appropriate for timber production in pure ponderosa pine stands but can be used to meet other resource needs. Water yields are not greater than from uncut forests. Individual-tree selection cutting provides minimum horizontal diversity in wildlife habitat but favors species attracted to vertically diverse forests. It also provides maximum partial retention of a natural appearing forest landscape. Group selection with very small openings accomplishes about the same things as individual-tree selection.

Intermediate harvests and thinnings can be used to produce an array of resource outputs and manipulate forage and cover for wildlife. They are primary tools for dealing with mountain pine beetle and have a profound effect on both the volume and value of forest products produced.

Not all resource needs can be met on a given site, nor is any one cutting method compatible with all uses. Land managers must recognize the potential multiple-use values of each area, determine the primary and secondary uses, and then select the management alternative that is most likely to enhance or protect these values within the limits imposed by stand conditions, damaging agents, and financial resources. On an individual site, some uses probably must be sacrificed or diminished to maintain the quantity and quality of others.

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Alexander, Robert R. 1987. Silvicultural systems, cutting methods, and cultural practices for Black Hills ponderosa pine. USDA Forest Service General Technical Report RM–139, 32 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Guidelines are provided to help forest managers and silviculturists develop even- and/or uneven-aged cutting methods and associated silvicultural practices needed to convert ponderosa pine forests in the Black Hills into managed stands, and maintain them, for a variety of resource needs. Guidelines consider stand conditions and insect susceptibility. Cutting practices are designed to maintain water quality, improve wildlife habitat, enhance opportunities for recreation and scenic viewing, with provide wood products.

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

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Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-140**

FORPLAN: An Evaluation of a Forest Planning Tool

Proceedings of a Symposium,
November 4-6, 1986, Denver, Colorado

Preface

The National Forest Management Act of 1976 requires comprehensive multi-resource plans for each national forest administered by the Forest Service. The planning process detailed in the Section 6 of the Act and the Section 6 Regulations which expand and interpret the planning and management requirements of the Act have resulted in the largest and most complicated planning analysis ever attempted by a natural resource agency. Much of this planning activity has focused on the mathematical programming procedure FORPLAN which was selected as the "tool" to support national forest planning. In the past 7 years, the Forest Service has dedicated a considerable amount of energy to completing FORPLAN analyses, and final forest plans are now beginning to emerge. As plans have been completed, client groups have directed substantial criticism at specific alternatives contained in the plans; but they have also extended their criticism to the FORPLAN process and its results. Criticisms of FORPLAN include: (1) the complexity of the process and results included in the plans mean that the logic supporting proposals can not be understood by client groups, (2) the FORPLAN model is inappropriate for many planning situations on national forests because of its emphasis on timber management, (3) the model is so complex that national forest specialists have difficulty implementing it correctly, and (4) that the models can be structured to produce plans that fit preconceived notions of "best" plans, thus, precluding balanced consideration of reasonable and perhaps preferred alternatives. Other criticisms have been made, but these serve to illustrate the controversy that has arisen around the FORPLAN model and process.

The Forest Service, Colorado State University, and Washington State University with the co-sponsorship of the American Forestry Association, organized the symposium for two reasons. The need for evaluations of FORPLAN by non-Forest Service experts was a major rationale for conducting the symposium, and the second and equally important reason was to provide an opportunity for Forest Service client groups and other interested people to participate in a review of FORPLAN.

Initially the symposium was structured to focus on the FORPLAN model, but the fact that the model is so tightly knit into the Forest Service's planning process resulted in the planning process itself being discussed as much or more than the model itself. This was reflected in every paper given at the symposium and in the discussions that followed presentation of the papers. The symposium was organized into three separate sessions which included presentation of papers by their authors, formal discussions of the papers, and open discussion with the symposium participants.

The first session was primarily dedicated to presentations by Forest Service personnel that described Forest Service development and use of FORPLAN. The objective of this session was to present an organized statement by the Forest Service. These papers covered: (1) the criteria used to select and implement FORPLAN, (2) the evolution of FORPLAN, (3) the operations research structure of FORPLAN, and (4) Forest Service experiences in using FORPLAN. In addition to the Forest Service presentations, the first session included papers by Dr. Dennis Teeguarden, who served as a member of the Committee of Scientists, and Dr. Norman Johnson, the principal architect of FORPLAN. This first session was a synopsis of an earlier Forest Service Workshop: Lessons from Using FORPLAN (USDA 1986).

The second session focused on experiences of state, province, private, and university organizations with FORPLAN. There were presentations by experts from California, British Columbia, Boise Cascade, and North Carolina State University.

Separate formal presentations evaluating FORPLAN from economic, ecological, and operations research perspectives were made in session three. These papers and the related presentations by discussions constituted the major evaluative phase of the symposium. Effective evaluation was facilitated through Forest Service and non-agency joint authorship. Charles Wilkinson's paper on the legal and political context of public land planning and management took a calculated look into the future during the banquet part of this session.

Dr. Roger Sedjo of Resources for the Future, and Dr. John Sessions of Oregon State University closed the symposium with summaries.

Rapid publication of these proceedings was made possible largely because most of the authors prepared their manuscripts on the Forest Service Data General system or other word processing equipment, and then submitted them electronically or on magnetic diskette. The manuscripts then were processed through computer-based usage and spelling checkers, and were put into camera-ready format. Because the papers are being printed with the content essentially as received, the authors are responsible for the accuracy of their papers; opinions expressed by the authors may not necessarily reflect the policy of the Forest Service or the U.S. Department of Agriculture.

USDA Forest Service
General Technical Report RM-140

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FORPLAN: An Evaluation of a Forest Planning Tool

Proceedings of a Symposium, November 4-6, 1986, Denver, Colorado

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Session I:

Development and Implementation of FORPLAN by the Forest Service.

Characterizations of the FORPLAN Analysis System

Thomas R. Mitchell and Brian M. Kent[1]

Abstract.--This paper provides an overview of a linear programming based system (FORPLAN) which is the principal analysis tool for land management planning on national forests. Topics discussed include how FORPLAN is used, the evolution and nature of the system, and the types of data input that are required.

Forest planning, as it is now carried out by the USDA Forest Service under the National Forest Management Act (NFMA), is a complex task that requires many varied analyses. These include an analysis of the capabilities of a National Forest (hereafter, forest) to produce goods and services; an analysis of issues, concerns, and opportunities facing management of a forest; analysis of social impacts; analysis of economic impacts; analysis of demands for goods and services; and analysis of cost efficiency. Central among these analyses is sorting through possible management options to identify the mix and timing of options that will yield the maximum net public benefit from management of the forest as a whole.

FORPLAN is a software package designed to aid this sorting and provide information regarding the combined effects of various mixes of management options. As such, FORPLAN is the central analysis tool used in forest planning. This paper discusses input to FORPLAN, reports that can be generated from FORPLAN, the differences between versions of FORPLAN, and how FORPLAN is used to accomplish required analyses.

In the discussion that follows, it is assumed that the reader has little or no background in forest planning, FORPLAN, or linear programming. Because a single paper cannot do justice to all these topics, every effort will be made to point the reader to other publications that can help increase understanding.

The Problem and One Method of Addressing It

A forest is managed by applying specific practices to specific areas on that forest. These practices are applied to help produce goods and services from a forest and to maintain the productivity of the forest. The practices applied, where they are applied, when they are applied, the sequence in which they are applied, and the standards under which they are applied all effect the amount, quality, and flow of goods and services. Also, the practices that are carried out determine, in large part, the costs of management of the forest. Briefly, then, the problem faced in forest planning is the choice of which practices are to be applied in what sequence to each area of the forest in order to produce the mix and flow of goods and services that will maximize net public benefit.

One way to address this problem is to subdivide a forest into distinct units. These distinct units are termed "Analysis Areas" (AAs). Resource data for each AA can be compiled to identify its capabilities for producing mixes of goods and services. Also, the feasibility of applying various practices and the probable effects of each practice on the production of goods and services from each AA can be assessed.

Based on such information, individual management practices can be grouped into sets that, when applied to a particular AA, will result in the achievement of specific objectives. These sets of practices, along with the standards governing how they are applied, represent the management options. Each set is referred to as a prescription (Rx). Each prescription is designed to achieve a specific management intent and produce a multiple-use mix of goods and services on a specific analysis area. A full range of prescriptions can be developed for each AA representing various possible management intents and mixes of goods and services.

Once a set of prescriptions has been developed for a specific analysis area, the results of applying each prescription can be displayed as shown in table 1. Because of the time span involved in management of a forest, this display can include several time periods (usually a decade in length) representing the sequence of practices and effects through time.

Numbers in table 1 represent what would happen if 1 acre of analysis area 135 were managed under each of the six choices or prescriptions. The prescriptions represent no harvest of timber (Rx 1351), shelterwood harvest (Rx 1352, 1353, 1354), or clearcutting of timber (Rx 1355 and 1356) at various times. As an example that may further clarify this table, the difference between Rx's 1355 and 1356 is that in the former, the acre would be clearcut in decade 3, while in the latter, it would be clearcut in decade 4. (If timing is the only difference between these two columns, then they represent different timing options or choices for a single Rx rather than different Rxs.)

A similar table could be developed for each analysis area. Further, these tables could be combined to create one

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Table 1.--Some implications in terms of costs and output levels for six prescriptions applied to analysis area 135.

	Prescriptions for AA 135					
Practices, costs & output levels of goods and services	1351	1352	1353	1354	1355	1356
Timber sale preparation decade 1	0	35	0	0	0	0
Timber sale preparation decade 2	0	0	35	0	30	0
Timber sale preparation decade 3	0	0	0	35	0	30

MCF timber decade 1	0	0	0	0	0	0
MCF timber decade 2	0	1.7	0	0	0	0
MCF timber decade 3	0	1.0	1.9	0	2.4	0
MCF timber decade 4	0	0	1.1	2.1	0	2.5
MCF timber decade 5	0	0	0	0.9	0	0

Preservation Visuals 1	1.0	1.0	1.0	1.0	1.0	1.0
Preservation Visuals 2	1.0	0	1.0	1.0	1.0	1.0
Preservation Visuals 3	1.0	0	0	1.0	0	1.0
Preservation Visuals 4	1.0	0	0	0	0	0

Wildlife forage decade 1	0	0	0	0	0	0
Wildlife forage decade 2	0	250	0	0	0	0
Wildlife forage decade 3	0	200	250	0	350	0

large matrix representing all prescriptions for all analysis areas on a Forest. This matrix, then, would be a display of all the possible management prescriptions for each analysis area, the costs of each of these prescriptions and the resulting quantity, quality and flow of goods and services.

At this point it would be possible to sort through this matrix to identify which prescriptions should be applied to each analysis area to produce a desired flow of goods and services through time from the forest. Because cost and benefit information is included in such a matrix, the set of prescriptions to be applied that will produce a desired mix of goods and services while maximizing cost efficiency could be identified.

This is not an easy task to do by hand. The number of analysis areas for a forest can range from 100 to 400 or more. The number of time periods considered must be at least 5 decades for all goods and services and for timber harvest scheduling questions at least 15 decades are usually considered. This means that such a matrix could grow to be 1,000 to 5,000 rows by 20,000 to 125,000 columns. A matrix of this size results in many numbers and choices to sort through to find the appropriate mix of prescriptions. The problem becomes even more complex when constraints representing production targets, policy limitations, etc. are added to the matrix. An automated procedure of some type would be very helpful here.

One such procedure is an operations research technique called "linear programming." Briefly, linear programming (LP) will sort through a mix of choices such as those represented in table 1 and identify the ones that will meet a set of objectives (desired mix of goods and services) while maximizing or minimizing a specific measure such as present net value.

From a simplistic viewpoint, an LP model consists of three components:[2]

1. A set of decision variables,
2. A set of constraints,
3. An objective function or criterion of optimality.

In a forest planning application, the decision variables or columns in the matrix represent timing choices for prescriptions for each AA. Constraints are rows in the matrix and represent: physical resource availability (i.e., the amount of land within each analysis area); production targets (i.e., produce so many recreation visitor days in a given decade); or restrictions (i.e., budget constraints).

An analysis task, then, is to translate information representing analysis areas and management prescriptions as shown in table 1 into the format of an LP problem. Once formulated, this problem is solved using a computer based LP solution package. The solution consists of the set of prescription timing choices that results in the largest (or smallest) possible value of the objective function subject to the limits imposed by all the constraints. Said another way, the solution shows the number of acres on each analysis area that should be managed by (or allocated to) each prescription timing choice (Kent 1980).

FORPLAN: An Overview of the System

It is possible to build an LP model (even a large one) by hand. However, early on in the process of developing forest plans it became obvious to Forest Service personnel that the development of some sort of automated procedure for doing so was almost a necessity. Two reasons for this are:

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[2] Except for this brief description, LP is not be discussed in detail here. It was developed in the 1940s (Dantzig 1963). For more details, refer to any introductory text on operations research (c.f. Hillier and Lieberman 1974), or to the LP manual by Kent (1980), or the paper by Bare and Field in these proceedings.

1. The skill level required to construct a large LP model by hand is considerable and persons having such skills would have to have been available on every forest.
2. The development of a standardized modeling approach, while difficult under any circumstance, would have been even more so if each forest staff developed their own approach to forest planning analysis.

As a result, a LP based system known as FORPLAN was chosen to be the principal tool for Forest planning analysis.[3] FORPLAN analysis involves three stages for the formulation and solution of an LP problem as shown in figure 1. Two of these directly involve FORPLAN; the other involves the use of the computerized LP solution procedure.

The first stage directly involves FORPLAN in building a linear programming matrix. Before FORPLAN is used, each forest needs to delineate analysis areas, develop management prescriptions for each and estimate costs, outputs, effects and benefits for each combination of prescription and analysis area. This is then coded for input into FORPLAN. After the user has prepared the FORPLAN input data (no small task), the FORPLAN matrix generator is used to edit this data for errors. Once any errors have been corrected, the matrix generator can be used to create the LP model data.

The second stage involves solving the LP problem. The matrix generated by FORPLAN in the first stage is used by the LP solution system (here, the Sperry Corporation proprietary system FMPS) to solve the resultant LP model.[4] Once this solution has been obtained, the second stage has been completed. Note that this stage does not directly involve FORPLAN.

Information about the optimal solution, as displayed by FMPS, is not readily understandable to people other than those trained in Operations Research techniques. Therefore, the third stage is necessary to interpret the implications of the solution in terms that are meaningful to an interdisciplinary team, the public, and decision makers. This task is accomplished by the FORPLAN report writer. The report writer uses the same input data as does the matrix generator, in addition to the optimal solution results. Its output is in the form of tables or graphs.

In short, a Forest uses FORPLAN to: (1) build a linear programming matrix representing management prescriptions designed to solve problems facing the Forest and to report the results of the optimal solution of this LP. Along the way, the FMPS system is used to solve the LP problem that FORPLAN generates.

Evolution of the FORPLAN System

FORPLAN was first made available for use by forests in 1980. As a result of lessons learned over the next 2 years, a second version[5] called Version 2 of FORPLAN was developed. (Details on some of the differences between the two versions will be presented later in this paper.) Again, as with Version 1, much of the development work was done by K. N. Johnson in close cooperation with Forest Service personnel.[6] After Johnson initially developed each version, the Forest Service took over maintenance, user support, and development activities.[7]

FORPLAN, as developed and supported in the Forest Service, is not a single software package that was developed once and held static. Rather, each version has gone through several needed changes as experience was gained in their use. To accommodate changing and upgrading FORPLAN, a system of releases within each version was used. Briefly, releases are modifications of a version of FORPLAN done to correct errors and to add needed features as identified by the user community. Each release is documented as to its input requirements and new features. Further, as new releases are issued, users are encouraged to change from one release to the next. Releases may be issued after a forest is already well into analysis, so switching may not be practical. Therefore, all releases being used by Forests are maintained and actively supported. Version 1 has 14 releases and Version 2 has 12 releases. About two-thirds of the forests used Version 1 for their planning analyses with the balance using Version 2.

FORPLAN Documentation

Over the past 3 years, a series of documents have been developed for each version. All but two of these are available from the LMP Systems Section in Fort Collins. The Overviews for each version have already been mentioned. For Version 1 there also is a Mathematical Programmer's Guide (MPG) (Kent, Kelly, and King 1985), a User's Guide (Kelly, Kent, Johnson, Jones 1986), and a Structures and Options Guide (Johnson and Crim 1986).

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[3] For more details on how this came about, refer to Russell (1986) and Jones (1986a). Most of the development work on this system had, at that time, been done by Dr. K. N. Johnson, now of Oregon State University, and it evolved from two earlier LP systems, Timber RAM (Navon 1971) and MUSYC (Johnson and Jones 1979), that had been used by the Forest Service.

[4] The use of the FMPS system in the solution of FORPLAN models is interesting. More details on this can be found in the paper by Kent, Kelly, and Flowers (1980).

[5] At this point, the original version became known as Version 1 of FORPLAN and is referred to by that name for the balance of this paper. The term FORPLAN without a version qualifier is used when both versions are being referred to.

[6] There are several references that provide additional details on this evolution. Detailed discussions can be found in the Version 1 Overview (Johnson 1986) and the Version 2 Overview (Johnson, Stuart, and Crim 1986). Iverson and Alston (1986) trace this evolution from a somewhat different viewpoint. Finally, the papers by Jones (1986b) and Weisz (1986) presented earlier in this symposium provide additional information.

[7] User support has been available both from Regional Offices and from the LMP Systems Section (Washington Office) in Fort Collins, Colorado. The Systems Section did the maintenance and development work. Training has been provided both by Regional Offices and the Systems Section.

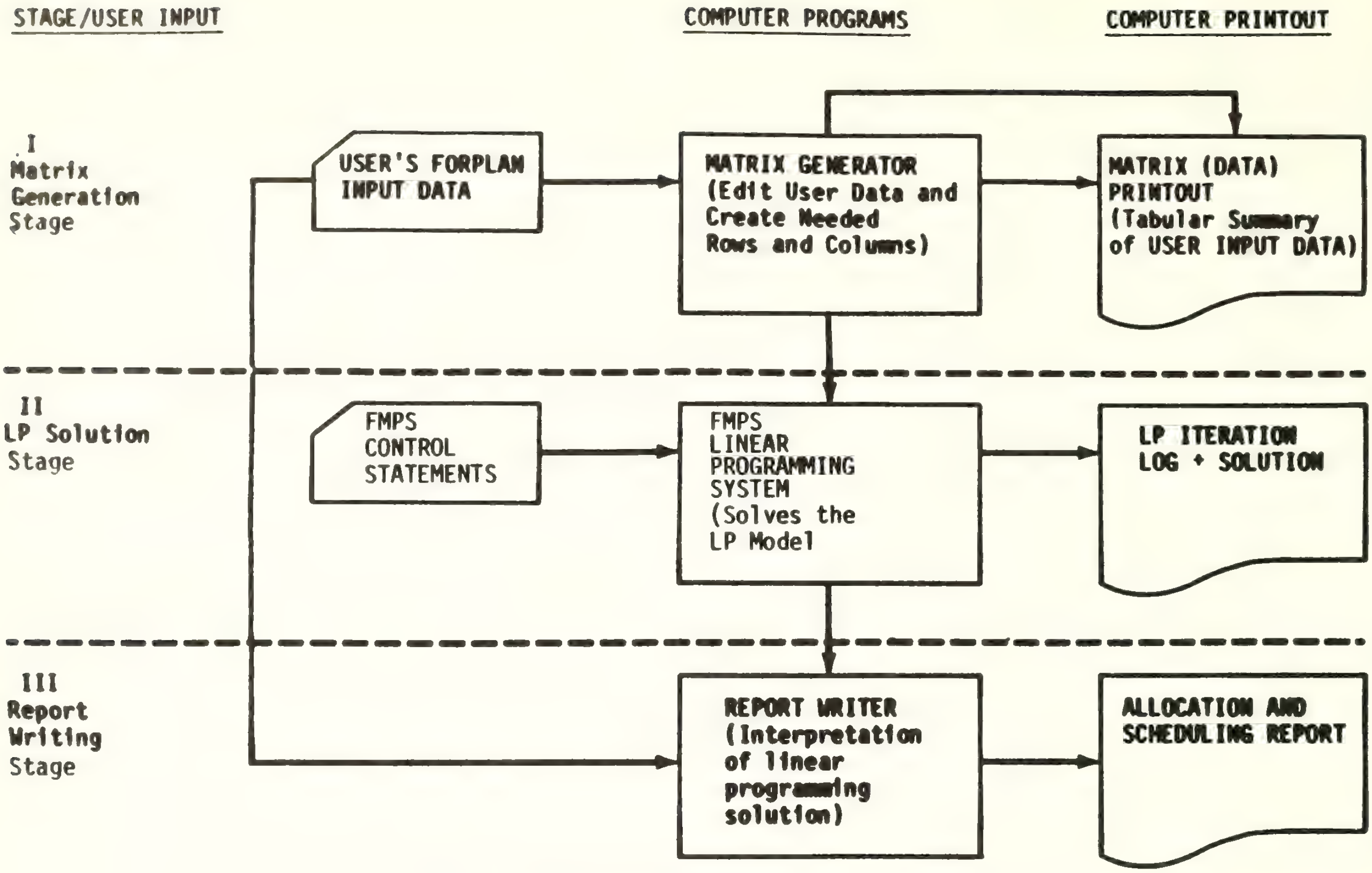
STAGE/USER INPUT
COMPUTER PROGRAMS
COMPUTER PRINTOUT
I Matrix Generation Stage
USER'S FORPLAN INPUT DATA
MATRIX GENERATOR (Edit User Data and Create Needed Rows and Columns)
MATRIX (DATA) PRINTOUT (Tabular Summary of USER INPUT DATA)
II LP Solution Stage
FMPS CONTROL STATEMENTS
FMPS LINEAR PROGRAMMING SYSTEM (Solves the LP Model
LP ITERATION LOG + SOLUTION
III Report Writing Stage
REPORT WRITER (Interpretation of linear programming solution)
ALLOCATION AND SCHEDULING REPORT

Figure 1.--System structure of FORPLAN (FORest PLANning model).

The MPG describes the mathematical relationships (constraints, objective functions, decision variables, etc.) that may be generated using Version 1. This document also contains some simple examples that are intended to show interrelationships between such things as analysis areas, prescriptions, etc. The User's Guide describes data input conventions and capabilities associated with the matrix generator. The Structures and Options Guide provides additional information on capabilities that the user can avail him or herself of. It also gives examples of the different LP model formulations or structures that Version 1 can provide.

The other documents that are available at this writing for Version 2 include a User's Guide (Gilbert et al. 1986), and an Operations Manual (Robinson, Kelly, and Bevers 1986). The User's Guide fulfills the same function for Version 2 as the Version 1 User's Guide does for Version 1. The Operations Manual describes how the Version 2 system interfaces with FMPS and with the Sperry Univac computer operating system.

Two additional Version 2 documents are in progress, an MPG (Johnson and Stuart, in press) and an Options Guide (Johnson, Crim, Stuart, and Kent, in press). These documents will also provide the same types of information as their Version 1 counterparts. The only difference is that the LP model formulations or structures are contained in the MPG.

The FORPLAN System vs. FORPLAN Models

Regardless of the version chosen, each forest is responsible for identifying how FORPLAN will be used to accomplish required analysis within the direction provided in the NFMA planning regulations (36 CFR 219) and within direction provided by the Chief's office and Regional offices. This includes identifying and structuring input to FORPLAN as well as identifying which version and features of FORPLAN that will be used.

These facts result in the development of a wide range of different FORPLAN models, because the forests vary considerably and the range of planning problems that must be addressed, varies considerably from forest to forest. Different forests will use different mixes of constraints, different features associated with the input data to the matrix generator, and different LP model formulations, depending on the nature of the problems they are trying to solve. In other words, while there are two FORPLAN versions, there are at least as many different FORPLAN models as there are forests.

Data Input to FORPLAN

As the previous discussion implies, the user has a range of options about what types of data and how much of any type (i.e., number of analysis areas, prescriptions, etc.) to provide as input to FORPLAN. However, there are certain general categories of information that are included in all FORPLAN models. These include:

1. Information regarding analysis areas. Each interdisciplinary team is responsible for subdividing their Forest into analysis areas and including these as input to FORPLAN.

2. Information regarding prescriptions for each analysis area. Again each forest is responsible for developing prescriptions for each analysis area. These are tailored on a forest by forest basis based on the particular problems to be addressed in forest Planning, characteristics of analysis areas used on each forest, and the range of practices and uses that can be applied and managed for on each analysis area.

3. Cost information is included for each practice included in each prescription. Also included are differences in costs of practices based both on analysis area characteristics and on differing standards for prescriptions.

4. "Yield Tables" containing estimates of production levels of goods and services that would result from application of prescriptions to analysis areas under the standards included for each prescription.

5. Benefit information representing both the direct dollar return from priced goods and services such as timber and forage for domestic livestock and estimates of dollar benefit values for goods and services for which there is no established market value such as dispersed recreation use.

6. Objective functions[8] and constraints. An objective function, as mentioned above, is the criterion of optimality to be used in determining the optimal solution. Examples include the maximization of present net value over the planning horizon, or the maximization of a good or service such as the production of elk winter range for 5 decades or the timber volume harvested in the first period. Constraints are used to impose targets on the production of goods and services. For example, forage for domestic livestock should be greater or equal to 90,000 AUMs in the first decade, timber harvest should be greater or equal to 40 MMBF in the first decade and the number of semi-primitive non-motorized recreation visitor days produced should be greater or equal to 400,000 RVDs in the first decade. Because of the way linear programming problems are structured, these desired levels are termed "right-hand-side values."

7. Report Selection Parameters. Both versions allow the user the choice of selecting which reports the report writer should print for a given run. These parameters are used to control this selection.

Following are more detailed discussions of some of the items just listed. Attempts will be made in these discussions to identify some of the differences between the two versions of FORPLAN.

Analysis Areas

Two types of analysis areas are typically used in FORPLAN. The first is termed a "homogeneous - noncontiguous" analysis area. Delineation of these analysis areas is based on the grouping together of similar land types, cover types, and timber age classes (e.g., a single AA on a forest could be all lands that have lodgepole pine *(Pinus contorta)* cover 100 to 120 years old, with moderate site productivity on stable soils and where natural regeneration is possible when clear cutting is used). Delineating and mapping this type of analysis area is easy based on the typical kinds of information available on a forest. Furthermore, development of prescriptions and estimating yields, costs, and benefits is straightforward because it is assumed that each acre of an analysis area will have the same response to practices. This type of analysis area is similar to area definitions used in Timber RAM and MUSYC and can be used in both Version 1 and Version 2.

The second type of analysis area is termed a "heterogeneous - contiguous" analysis area. These represent distinct and definable geographic areas such as watersheds or range allotments. With this type of analysis area, such things as range management, vegetative diversity, and the production of goods and services which rely on the spatial arrangement of different types and conditions of cover are easier to represent in an LP model than they are with the homogeneous - noncontiguous analysis areas. Furthermore, representing such things as costs, output levels of goods and services and probable use of a specific area on the Forest is easier. However, use of this type of analysis area means that development of prescriptions and timing options is not as straight forward or as easy to accomplish. Realistically, this type of analysis area can only be used in Version 2, and the need to use such an analysis area to address specific problems was one of the primary motivations behind the development of this version.

In Version 1, the types of information used to characterize analysis areas is fixed. It consists of a set of "identifiers" or names for the strata that are used to delineate analysis area boundaries, an initial age for each analysis area, and the area of the analysis area. For more details on this, refer to Section 5 of the Version 1 User's Guide (Kelly et al. 1986) or to Section 1.4 of the Version 1 MPG (Kent et al. 1985).

In Version 2, the user can characterize analysis areas in the same manner as in Version 1 except that age is not specified. However, to provide as much generality as possible, the user does not have to specify any characteristics of an analysis area other than its size. Any combination in between also is possible. For more details, refer to Sections 5 and 9 of the Version 2 User's Guide (Gilbert et al. 1982).

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[8] Version 1 can generate only a single objective function in any given matrix generation, while in Version 2, up to five objective functions may be generated (of course only one can be optimized at a time regardless of version).

Prescriptions

A prescription is a specific set of practices to be applied at a specified time and in a specified sequence to an analysis area using a specified set of standards. In Version 1, prescriptions fall into one of two[9] categories, prescriptions that involve the harvest of timber and those that don't. For more details on this, see Section 6 of the Version 1 User's Guide (Kelly et al. 1986) or Section 1.4 of the Version 1 MPG (Kent et al. 1985). Briefly, prescriptions in this version are characterized, in part, by the following user input data:

Data Item	Brief Description
1. prescription number	a label for the prescription
2. analysis area number	identify the analysis area to which it applies
3. management emphasis	the management philosophy for the prescription
4. management intensity	the level of investment for the prescription
5. table numbers for economic and yield tables	pointers to tell the FORPLAN programs where to get economic and yield information for the prescription
6. information on timing choices to be generated	determines which timing choices for implementation, thinning, and harvesting the matrix generator will consider for the prescription

This information is used by the matrix generator to develop the decision variables (columns) for each of the timing choices for each of the prescriptions the user specifies.

Early on in the use of Version 1, it became obvious that this structure for representing prescription data had two major deficiencies.

1. There was too much of a "block box" aura concerning how the matrix generator used information on yields, economics, timing choices, etc. to represent prescriptions in a FORPLAN model.
2. Data input was tedious and lengthy because all information had to be entered for each prescription no matter how repetitive it might be.

Attempts were made to address both of these problems in designing Version 2. A new approach for representing prescriptions, known as directly entered (DE) prescriptions was incorporated. In this approach, rather than relying on the matrix generator to use yield, cost and benefit tables to build prescription timing choices, the user must enter all such information column by column for each prescription timing choice to be represented in the model. This solves the "block box" problem because every implication of every prescription is explicitly entered by the user.

This type of prescription was primarily developed for and used with the heterogeneous - contiguous analysis areas. Use of this type of analysis area and a DE prescription allows an interdisciplinary team to design development and management of a specific geographic area on a Forest, and record all the practices, costs, output levels, and benefits that would occur under the resultant prescription. While the DE feature provides an almost unlimited capability to tailor management options for specific locations, it also requires much time and work. There are two disadvantages.

1. Analysis of timber harvest scheduling problems requires that many timing options be considered - from a practical standpoint this can become almost impossible using only DE prescriptions.
2. The amount of input necessary for directly entering prescriptions can be large (considerably larger than in Version 1) and thereby make checking for coding and keypunching errors very difficult and time consuming.

As is evidenced by the previous sentence, while DE prescriptions resolved much of the "black box" problem, they did nothing to improve the ease of data input. To resolve this second problem, which stems from a requirement to repeatedly enter a piece of data every time it is used, an option called "theming" was incorporated in Version 2. This option allows the user to "theme" repetitive information associated with prescriptions to one or more general characteristics associated with a group of prescriptions. These characteristics typically relate both to the prescriptions and to the analysis areas to which they apply.

For example, one analysis area could contain lodgepole pine 100 to 120 years old, while another could be exactly the same except that the age of the timber was 80 to 100 years. The basic prescriptions for each could be the same. The only difference would be a reflection of the age differences in terms of yields, etc. In Version 1 or in DE prescriptions in Version 2, all information about identical prescriptions would need to be repeated for each analysis area. As an alternative in Version 2, identical information could be "themed" to both analysis areas, keying off the common property that they are stands of lodgepole pine. It then would only have to be entered one time in the data set. More information on both DE prescriptions and theming can be found in the Version 2 Overview (Johnson, Stuart, and Crim 1986) and in the Version 2 User's Guide (Gilbert et al. 1986).

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[9] Actually there are three categories as prescriptions that involve timber harvest are further subdivided into prescriptions for existing stands (those that exist at the beginning of the planning horizon) and prescriptions for regenerated stands (those established after the start of the planning horizon).

Yields, Costs, Benefits

In the discussion that follows: yields refers to physical levels of production for an output; benefits refers to returns from the production of outputs; and activities refers to practices and associated costs. Regardless of the version chosen, these three items are represented in much the same fashion and so, will be discussed together.

In Version 1, there is the capability to represent 11 activities or outputs on a decade by decade basis. These can include, for example, output levels of timber, forage available for wildlife, or any other activities or outputs that will change through time. For each of these, additional economic measures representing costs and benefits can be included as appropriate. In addition, Version 1 provides the capability for tracking 10 additional measures such as categories of recreation opportunities (e.g., semi-primitive non-motorized recreation) that will result from application of a prescription to an analysis area. These are viewed as a function of such an application and will not change over time. For more details on this, refer to Section 8 of the Version 1 User's Guide (Kelly et al. 1986).

Again, as with prescription data input, early experience with Version 1 quickly showed that the ability to track more activities and outputs was needed. Therefore, Version 2 was designed to allow up to 200.

Version 2 uses tables similar to those in Version 1 to provide input for matrix generation and report writing. Such tables can be used both with the theming option and when directly entering prescriptions. Beyond this, as was discussed previously, amounts of practices, costs, production levels of goods and services, effects, and benefit values can be entered directly without using yield tables. For more details on this, refer to Section 5 of the Version 2 Overview (Johnson, Stuart, and Crim 1986) or to Section 9 of the Version 2 User's Guide (Gilbert et al. 1986).

Besides these capabilities, Version 2 also offers the user an option (called common economics) for inputting commonly used economic values. This works in a fashion similar to the theming option described above. See Section 3 of the Version 2 User's Guide (Gilbert et al. 1986) for more details on this.

Before concluding the discussion of yield and economic information, two more points need to be made. First, it should be understood that except for a few specialized timber related coefficients[10] neither version of FORPLAN is, in any way, a coefficient generator. Said another way, all yield and economic information is used in the form that it is input by the user. Thus, the second point is that this information represents estimates that are obtained from non-FORPLAN related sources such as simulation models etc.

Constraints

Three types of constraints can be specified in an LP:[11]

1. Equality constraints.
2. Upper limit constraints (maximum, less than or equal to).
3. Lower limit constraints (minimum, greater than or equal to).

Equality constraints provide a number that must be equaled. Upper limit constraints give a maximum that must not be exceeded. Lower limit constraints give a minimum value that must, at least, be achieved.

There are two general classes of constraints available in either version of FORPLAN.

1. Constraints implicitly designated when the user selects a particular model formulation. For the most part, these constraints relate to land or acreage accounting; i.e., they ensure that only the acres on a given analysis area are represented in the analysis.
2. Constraints explicitly designated by the user. There are a wide variety of these constraints, and they are typically used to incorporate the many restrictions that control management of a forest. Many of these restrictions stem from policy requirements such as the policy to harvest timber under non-declining yield. These constraints are also used to reflect production targets that must be met.

Table 2 shows categories of explicit constraints that can be represented in Version 1 models, while table 3 provides the same information for Version 2. More information on all these constraints can be found in any of the FORPLAN documents cited previously.

Reports

As has been mentioned previously, both versions of FORPLAN offer the user a wide variety of printed reports that may be generated in a given run. Briefly, a set of reports for either version consists of a title page showing the status of the LP solution, a report showing summaries of all the constraints based on the output from FMPS and then a series of tables and graphs.

The first two reports are always produced in Version 1 but may be suppressed in Version 2. However, for either version, the user has the option of specifying how many tables and graphs are to be printed. Following is a brief list of reports that may be obtained when using Version 1.[12]

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[10] For Version 1, refer to Appendices II, III, and IV of the Structures and Options Guide (Johnson and Crim 1986) and for Version 2, refer to Section 7.4 of the User's Guide (Gilbert et al. 1986).

[11] The material on constraints is taken from the Version 1 Overview (Johnson 1986) and from the Version 2 Overview (Johnson, Stuart, and Crim 1986).

[12] This list and the comments are taken from the Version 1 Overview (Johnson 1986).

Table 2.--Constraints that may be explicitly designated in Version 1.

Constraint	Equality	Lower limit	Upper limit	Function
Prescription acreage	X	X	X	Controls amount or proportion of an analysis area assigned to a prescription.
Analysis area accessibility			X	Sets an upper limit on the proportion of analysis area acreage that could have been treated (in any way) up to and including the period in question.
Cultural treatment and financial				
Acreage restocked			X	Sets an upper limit on the area of nonstocked land that can be regenerated per period on the forest.
Acreage of improved stock planted			X	Sets an upper limit on the area of improved yield that can be regenerated per period on the forest.
Acreage of precommercial thinning			X	Sets an upper limit on the area of precommercial thinning that can be done per period on the forest.
Total cost			X	Sets a maximum budget that can be spent per period on the forest.
Total revenue		X		Sets a minimum revenue that must be obtained per period from the forest.
Scheduled output	X	X	X	Controls the area of timber harvested, volume of timber cut, or volume of some scheduled output produced per period forest-wide or on some portion of the forest. Area constraints can be set up as absolute amounts or as a proportion of the area allocated to specific emphases or intensities.
Inventory acreage	X	X	X	Controls area in specified range of age classes per period forest-wide or on some portion of the forest. Constraints can be set up as absolute amounts of area or as a portion of the area allocated to specific emphases or intensities.
Nonscheduled output	X	X	X	Controls amount of nonscheduled output allowed forest-wide or on some portion of the forest.
Management emphasis and intensity	X	X	X	Controls area allocated to a particular management emphasis or management intensity forest-wide or on some portion of the forest.
Timber harvest flow				
Nondeclining yield		X		Requires that the timber harvest volume produced on the forest not decline from period to period.
Sequential lower bound		X		Requires that the timber harvest volume produced on the forest not decline at more than a certain rate from period to period.
Sequential lower and upper bound		X	X	Requires that the timber harvest volume produced on the forest not decline at more than a certain rate from period to period nor increase at more than a certain rate per period.
Arbitrary control		X	X	Requires that the timber harvest volume per period produced on the forest stay between specified amounts.
Nondeclining yield-sustained yield link	X		X	Requires that the nondeclining yield timber harvest volume produced on the forest in the last period stay at or below the long-term sustained-yield capacity associated with the management intensities and rotation ages selected in the linear programming solution.
Ending inventory		X		Requires that the inventory volume left on the forest at the planning horizon at least equal the average inventory on a forest managed with the management intensities and rotation ages selected in the linear programming solution.
Long-term sustained-yield constraint	X	X		Controls the level of the long-term sustained-yield capacity produced on the forest.
Timber growth constraint	X	X		Controls the timber volume growth per period produced on the forest.

Table 3.--Constraints that may be explicitly designated in Version 2.

Constraint	Equality	Lower limit	Upper limit	Function
Absolute	X	X	X	Control the physical or financial amount of some activity/output that can occur in some period.
Flow	X	X	X	Control the physical or financial rate at which some activity/output can change from period to period.
General relational	X	X	X	Control the proportional relation between two sets of acres, a set of acres and an activity/output or two activity/outputs in some period.
Budget and Revenue				
Total cost	X		X	Sets a maximum budget that can be spent per period.
Total revenue	X	X		Sets a minimum revenue that must be obtained per period.
Allowable sale quantity				
Non-declining yield		X		Requires that the timber sale volume not decline from period to period.
Sequential		X	X	Requires that the timber sale volume not decline at more than a certain rate from period to period nor increase at more than a certain rate from period to period.
Absolute	X	X	X	Requires that the timber sale volume stay between specified amounts in particular periods.
Nondeclining yield - sustained link	X		X	Requires that declining yield timber sale volume in the last period stay below the long-term sustained-yield capacity associated with the management intensities and rotation ages selected in the linear programming solution.
Perpetual timber harvest			X	Requires that the inventory volume left on the forest at the planning horizon at least equal the average inventory on a forest managed with the management intensities and rotation ages selected in the linear programming solution.
Long-term sustained-yield capacity constraint	X	X	X	Controls the level of the long-term sustained-yield capacity.
Timber growth constraint	X	X	X	Controls the timber volume growth as an absolute amount or as a proportion of the long-term sustained-yield capacity.
Prescription controls	X	X	X	Controls amount or proportion of an analysis area assigned to a prescription or group of prescriptions.

Land Allocation Reports

Some reports cover allocation of the land to prescriptions. Reports produced include:

1. Allocation of analysis areas among management emphases.
2. Allocation of aggregate areas among aggregate emphases.[13]

Scheduling Reports

A series of reports deals with the scheduling of management prescriptions over time and the resulting activities, outputs, costs, and returns. Reports produced include:

1. The timber harvest (summary).
2. The timber harvest by prescription.
3. Harvest of existing and future stands.
4. Timber inventory, harvest, and growth.
5. Timber inventory acreage by class.
6. Scheduled outputs (including timber) by prescription.
7. Scheduled outputs (including timber) by identifier.
8. Timber detail by a series of different measures.
9. Cultural treatments.

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[13] For details on aggregate areas and aggregate emphases, see Section 4 of the Version 1 MPG (Kent et al. 1985).

Scheduling Graphs

FORPLAN produces a wide variety of scheduling graphs that portray the results over time. Timber RAM (Navon 1971) produced a scheduling graph showing the timber harvest volume in each period and, its popularity with users caused the creation of several additional graphs. Graphs produced include:

1. Total timber harvest volume and sustained yield.
2. Total timber harvest volume, timber growth volume, and timber inventory volume.
3. Area of regeneration.
4. Area of precommercial thinning, release, and other cultural treatment.
5. Area of existing timber in each period that was older than 10 periods at the start of the planning horizon.
6. Timber inventory acreage by age class.
7. Area harvested and timber volume removed by harvest type.
8. Acres harvested and timber volume removed by land class.
9. Acres harvested and timber volume removed by working group.
10. Inventory volume by working group and by land class.

Economic Reports

FORPLAN produces several economic reports covering the planning periods. Reports produced include:

1. Standard cost categories in prescription economic tables.
2. Scheduled output volume, cost, and value.
3. Timber value, total value, and total cost.
4. Net revenue, present net worth, net benefit, and present net benefit.
5. Undiscounted costs and returns.
6. Total discounted costs, total value, and value for each scheduled output by period.
7. Discounted economic data for the planning horizon in total and by scheduled output.

The user has even more flexibility in selecting reports from Version 2. To quote from the Version 2 Overview:[14]

> "Beyond a forestwide report that gives the level of each activity and output per period and the associated financial effects, and a forestwide report that gives the levels of different treatment types (such as clearcutting) per period, all reports in Version 2 are optional. Reports similar to the forestwide report can be produced for each prescription in the solution for designated analysis areas or zones and/or for all prescriptions in the solution for designated analysis areas. Also, a wide variety of reports can be created by the user to extract the particular aspects of the problem that are of interest for specified analysis areas or zones. These latter reports can be specified for (1) activities, outputs, and combinations of activities and outputs; (2) acres and volumes by treatment type and stand characteristics; (3) age class acreage; and (4) inventory volume, harvest, and growth."

How Is FORPLAN Used?

FORPLAN is the central analysis tool in Forest Planning. This section provides a brief description of how it is used both for the development of planning alternatives and for accounting purposes. Detailed discussions and case studies are presented in the two Overview documents (Johnson 1986 and Johnson, Stuart, and Crim 1986).

There are 4 planning actions of the 10 identified by the NFMA regulations (USDA FS 1982 36 CFR 219.12) closely associated with these activities and, therefore, with the use of FORPLAN. These are:

1. Analysis of the management situation.
2. Formulation of alternatives.
3. Estimation of effects of alternatives.
4. Evaluation of alternatives.

Analysis of the management situation includes development of benchmark alternatives. These are used to characterize the ability of a given National Forest to produce goods and services. This analysis provides a framework for developing the second set of alternatives during the second planning action in the above list. Alternatives in this second set must cover a wide range of possibilities within the framework developed during benchmark analysis. It is from this second set that a preferred alternative will be selected.

Each alternative, regardless of type, requires one FORPLAN run. Differences between alternatives are reflected in the FORPLAN data primarily by varying the types of prescriptions that are considered and by varying the constraints that are imposed on the model.

LP models (and, therefore, FORPLAN) are useful accounting tools, as has been mentioned previously. That is, the results of the solution can be interpreted by the report writer to provide a wealth of information on items such as production levels of outputs, costs incurred, the allocation of land area to prescriptions, etc. Thus, the information needed[15] to accomplish the planning steps involving the estimation of effects of alternatives and the evolution of alternatives is in large part, available from reports produced by FORPLAN.

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[14] Johnson, Stuart, and Crim 1986, op. cit.

[15] This is true only for those aspects of the planning alternatives that have been quantified and included in the FORPLAN model.

We close this section of the paper with a few observations on the development of a FORPLAN data set and the analysis that follows. Many of these have already been made previously; the purpose here being to provide a summary of some important points. As can be gathered from the preceding discussion, there is a considerable amount and variety of data that must be acquired and organized into a format acceptable to FORPLAN. Therefore, much time and effort goes into just assembling a FORPLAN data set. Once this is done, the data must be edited by the matrix generator and all errors must be corrected. Then several LP runs must be made to calibrate the data set; i.e., to determine both how well it reflects the forest being modeled and how well it addresses the planning problems that have been identified. Only after this is done can actual alternative development be undertaken. Of course, continued refinement of the data set occurs based on the information gained during alternative formulation.

Conclusions

This completes what is intended to be an overview of the two FORPLAN versions and how they are used in Forest Planning. Many topics have either been only briefly mentioned or have not been covered at all. The interested reader can learn more about these topics and the ones discussed in this paper by referring to the papers and publications cited. Also, the other papers present in this symposium will also provide additional information.

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History of the Criteria Defined by NFMA and Used in the Selection and Implementation of FORPLAN

John W. (Bill) Russell[1]

Abstract.--The criteria for selection and implementation of FORPLAN as the primary analysis tool for forest planning initially arose from the conditions which led to the Monongahela lawsuit. Later, the criteria were influenced by NFMA, the NFMA regulations, and by efforts to comply with those regulations. This discussion of the events before and after NFMA provides a non-technical historical perspective of the decision to use FORPLAN and later to develop Version II FORPLAN.

Introduction

FORPLAN was designated as the "primary analysis tool for the Forest plans." The rationale for this decision can best be understood within the context of the events leading up to the National Forest Management Act and those events that occurred during formulation of the regulations. Still other events influenced the many successful applications of this planning tool and the management of implementing FORPLAN.

Three criteria resulted in the designation, use, and development of FORPLAN as the primary analysis tool: (1) the technical, (2) the planning process, and (3) total management needs. The first two, the technical and planning reasons, are criteria either established by, or interpreted as being established, by NFMA and the regulations.

The technical reasons could include, for example, the need for determining allowable sale quantity or long term sustained yield, the effects of minimum management requirements, etc.

Planning process needs might include the consideration of multiple-uses or resources in determining the management emphasis and in scheduling to "form one integrated plan for each unit of the National Forest System" as required by NFMA.

The management reasons might include the need for consistency in Forest planning methods or results to get on with the job of plan development and approval in implementing the National Forest Management Act.

Each of these criteria was influenced by or was an influence on events leading up to NFMA and later the decision about, and the use of, FORPLAN. Therefore, our focus on the reasons for a standard computerized planning model might begin with the planning process and its management as it was between 1970 and 1976.

1971

Unit planning was in progress. There were 1,601 planning units identified in the National Forests. In 1976, there were 493 unit plan draft or final environmental impact statements filed or under preparation and the estimated date of completion of unit planning nationwide was 1985. There were many concerns about the incremental approach of unit planning. For example, the allocation for the last few units of a National Forest might require a total re-analysis for the entire Forest, i.e., "last unit in re-allocation analysis" fear.

Also, at that time there were at least 48 different types of functional plans being required for various purposes. The only resource plan that covered an entire National Forest was the timber management plan. Other resource plans were generally prepared only if significant amounts of the resource existed (General Accounting Office 1978).

Multiple use guides provided general policy direction, but did not set goals for resource development. These were to be established in resource management plans. District Rangers were required to prepare a multiple use survey in which they considered the impacts of proposed projects on the multiple use resources. The guides and surveys did not always result in adequate multiple-use planning. The on-the-ground results that generated increasing public resistance to timber harvest are well illustrated in the challenges that eventually resulted in the NFMA.

Area guide development was also under way.[2] These were designed to be a key interface with other regional programs in study areas. The intent was to aggregate Forest and unit capabilities for use in the RPA Assessment. Much study and development work was underway to make the Forest Service Management Model operational by developing the hierarchy of planning. Standard outputs and activities definitions were defined as information requirements in the Management Information handbook.

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[1] Director of Land Management Planning, Southwestern Region, USDA Forest Service.

[2] USDA Forest Service. 1973-1985. Numerous memos, letters and documents.

The Project INFORM (Information for Managers) staff was disbanded in 1975 after marginal success in developing standard resource data bases. This group was initially formed about 1971, the same year the Forest Service Blueprint for Action recommended increased control, compatibility, support and coordination, and training for computer use.

Many line officers in the field were concerned about the appearance of a top down or centralized approach in mandating process. For example, in 1976, one Forest Supervisor wrote, in part, about area planning: "The attempt (by the WO) again seems to be to standardize a process without clearly defining the reasons for doing so...(there is the need to) become "end product oriented," and leave the "how-to's" to those expected to provide him (the Chief) with what he needs."

Just before this at the 1975 summer RF&D meeting held at Fort Collins at the Computer Center, the focus had been on Systems Development, Organization, and Management. At this meeting, the Chief and RF&D were provided with descriptions of some thirty plus different planning processes, flow charts, and PERT diagrams; a bewildering display of apparent inconsistency in planning approaches. A major objective of the meeting was to decide how to (1) organize; i.e., centralize or decentralize systems training and development staffing, (2) determine the level of effort needed, and (3) establish a time frame for implementation of actions or programs.

Besides recognizing the number and diversity of planning processes, other areas of concern at this RF&D meeting were: the lack of uniformity of data definitions and standards; lack of data and analytical support for assessment and program development and subsequent allocation; fragmented independent design efforts in developing a coordinated management information system; and a basic disagreement on computer system management and lack of adequate effort to develop, operate, and trouble shoot computer systems including lack of training.

The Systems Development Action Planning Team (SDAPT) was chartered to examine these problems in greater detail and make recommendations for their resolution. This team was headed by Doug Liesz, Regional Forester in Region Five at that time. The team recommended strengthening national leadership for hardware, software and data bases. A major reorganization and redefinition of national responsibilities resulted. A second Associate Deputy Chief for Administration was assigned responsibilities for systems. (The SDAPT recommendations were revisited during the Systems Review Team effort chaired by Regional Forester Jean Hassell in 1984. The original SDAPT team felt their recommendations had been mostly met but there were new challenges.)

The General Situation, 1970-1976.

Now enters the Court of Appeals for the Fourth Circuit ruling on the Monongahela, the NFMA amendment to the Resources Planning Act, and the requirement for an interdisciplinary planning process and an integrated plan for each administrative unit. Final planning regulations (or semi-final, depending on your point of view) were issued on September 17, 1979 (Oregon Law Review 1985). These regulations were revised and promulgated again on September 30, 1982.

Before passage of NFMA, various staffs in the Washington Office under the leadership of Timber Management and Land Management Planning, had been working on strategy plans to implement NFMA. These plans were also used to provide information to Legislative Affairs on the effects of choices being considered in the legislation.

The strategies depended heavily on field input, such as a series of questionnaires responded to by Forest resource staff specialists, District Rangers, and Regional Office planning specialists from around the country. In addition, the new Systems Application Unit for Land Management Planning (SAU-LMP) provided staff support for formulating national strategy. This unit was formed primarily from the Watershed Development Unit that was moved from Berkeley, California, to Fort Collins, Colo. in 1973. This unit was responsible for the Resource Capability System, later renamed Resource Allocation Analysis.

Responses from the various field sources generally focused on the need to eliminate functional resource inventories and incremental planning. Several papers written by SAU-LMP (Bottoms 1975) formed a basis for using a "systems approach" to "natural resource decision analysis" including the need for mathematical solutions as a basis for resource allocation and similar decisions. This philosophy provided the core concept of the proposed integrated planning process before and after passage of NFMA.

Initially, a WO strategy and tactics overview provided coordination direction and responsibility for various staffs working at all levels of the organization. A work plan for Implementation of the NFMA provided more specific direction. For example, several end products needed for implementing NFMA were described with the primary responsibility for the final product, for developing and maintaining the product, assistance to be provided, staffs to advise and review, and the final approving authority, e.g., Regional Forester, Deputy Chief, or Chief.

The end products identified included Lead Forest Work Plans, Forest Planning Criteria, revised Forest Service Manual 1900, Draft FSM 1920, Regulation comments (also for use with the Committee of Scientists), RARE II data base, Regional Plans, Lead Forest draft and final environmental impact statements and Forest Plan, and revised FSM direction for each resource area.

A network of coordinators was set up for communication. This included a 1900 core team including coordinators from all Deputy areas, and a resource team (or interdisciplinary team) within the NFS Deputy Chief area of responsibility. Associate Deputy Chiefs provided a steering or oversight function. The Regional Planners and the Forest Planners and Forest Supervisors for Lead Forests were a part of the coordinating network.

The lead Forest planning program was established to "provide a basis for the incorporation of recommendations and guidelines in the FSM and FS Handbook." The objective of monitoring the procedures used by lead Forests was to (1) test the feasibility and effectiveness of the applied methods and procedures used to produce a given product (DEIS, FEIS, or Forest Plan): and (2) to evaluate feasibility and practicality of the NFMA regulations. Periodically the Lead Forests met to compare notes, experiences and products and the proceedings were documented and distributed.

There were as many variations in techniques as there were lead Forests (initially one from each Region). Other Forests were not sitting idly by either. Many Forests felt obligated to begin planning for many reasons. The techniques used varied from mapping overlays similar to techniques used in urban planning and more sophisticated computer mapping techniques such as MIADS2 and its modifications. The techniques also included the use of a budget programming method, i.e., ADVENT, and other mathematical techniques, including Goal Programming.

There was some very good planning going on. The National policy had been to permit each region to experiment how planning was to be accomplished to promote innovation. The only standard for planning was past plans and a "good" plan was the standard only until a "better" plan was done (General Accounting Office 1978).

Based on the experience of lead Forests in attempting to meet the new NFMA regulations, Timber Management and Land Management Planning agreed that some standard approach was needed if Forest Plans were going to have any common basis and be usable for the RPA Assessment, RPA Program, and budget proposals.

First Regulations Issued September 17, 1979

The regulations developed for NFMA were interpreted to require an optimization technique for both allocation and for scheduling. Experiences in unit planning used such allocation techniques to assign management emphasis to land areas. Timber management planning had also historically used optimization for timber harvest scheduling. The regulations were developed knowing that these two basic needs and approaches represented the state of the art in planning.

The practical choices of optimization techniques were limited to three systems: (1) Integrated Resource Planning Model (IRPM) (Kirby et al. 1980), Resources Capability System (RCS or RAA), and (3) Timber Resource Allocation Method (RAM) (Navon 1971) or an ongoing revision of RAM called Multiple-Use Sustained-Yield resource scheduling Calculation (MUSYC) (Johnson and Jones 1979, Iverson and Alston 1986, Johnson et al. 1986).

Although RCS had been used in several unit plans and on at least two national forests for planning, Timber RAM had been widely used and represented the greatest reservoir of experience and skill in optimization use in the Forest Service at that time. MUSYC provided some capability for multiple-use analysis already. Besides meeting the intensive requirements for timber harvest analysis required in NFMA and the regulations, MUSYC could be modified to consider other resources equally and simultaneously to meet other requirements. Not only were there people trained and already using RAM/MUSYC, there was ongoing commitment by the Forest Service and by Norm Johnson to provide support for its use and improvement.

So RAM/MUSYC was renamed FORPLAN and responsibility for its support was shifted from TM to LMP. For many technical reasons Version II of FORPLAN was later developed, including the need for easier data entry, spatial definition, increased capacity for other resource or use variables and other needs identified by forest analysts. Not the least of these reasons was the ability to use the standard outputs and activities of the MIH to provide a direct link to the budget and RPA. It was also hoped that Version II would be more readily learned and promote interaction between forest interdisciplinary team members.

Each Forest Supervisor and planning staff went through two weeks of awareness training that included discussions of optimization. Computer conferences were used to provide up-to-date training and to identify and solve problems in software and computer use. National and regional training sessions on the use of FORPLAN were held. The WO Systems Application Unit for Land Management Planning provided direct assistance to many forests both by phone and by travel to the unit. A hot-line for FORPLAN handled as many as 200 or more phone calls per day. A Version-Release system enabled users to know precisely what worked and what did not and provided a key to the documentation that was constantly being revised in response to suggestions by forest planners and analysts.

When new and more stringent national standards and guidelines dramatically increased the emphasis on economic values and analysis, most Forests were forced to totally re-formulate their planning models to comply. As draft plans were reviewed, planning models were revised, supplemented, or even re-formulated again. Some draft plans were re-drafted and re-issued.

The "Human Element"

Recalling these hectic times of turmoil and change in forest planning and analysis prompts a word or two about the "human element" of FORPLAN that tends to be overlooked in most discussions and writings on the subject. This refers to the enthusiasm of planners and analysts on the national forests; the frustrations and blood, sweat and tears of those people; referring to the long days and nights and weekends that so many people put in because they believed in what they were doing; referring to the personal stress that manifested itself differently in different people but inevitably took its toll in each of us who were committed to doing the job right.

This subject probably requires a separate and undoubtedly lengthy paper. But for those who know who you are, you will remember when you hear or read this that the story of FORPLAN is not computers, or models, or data; it is dedicated people who care about doing good professional analysis. Many of these people came to support a standardized approach to a complex problem. It was the most efficient way to adapt to changes in national direction and need, a philosophy that continues to be useful.

Today and Tomorrow

However, even with these constant shifts toward standard use of a required analytical tool, i.e., more standard model formulation, there is today, a great variation in results. Regional summaries of draft and final planning data for use in program proposals, budget allocation, and other management information have pointed out differences Forest by Forest.

Besides the need to add up or summarize outputs and costs, acreage summaries are increasingly important. One important thing learned from Forest Plans is that many people did not know what the Forest Service did until we showed them our draft plans. Now we must be able to show them we have made progress in the past and plan to make more progress in managing unsuitable or unsatisfactory conditions, e.g., watershed, grazing, wildlife habitat, etc.

As we monitor and amend Forest Plans, some of these pressures and management needs will require us to continue to standardize our resource data and management information. Experience with a standard computerized model to date indicates we will still have differences ten years or so from now. But there are a lot of useful similarities in planning process and management information today as a result of yesterdays decisions to standardize.

There is an increased need for the expertise gained in Forest Planning. Analysts must do more than assemble data and provide results. Analysts must move closer to decisionmaking and into a mainstream information management role. We have done a good job in Forest Planning, and with the expertise and the communication and computing power we now have, the opportunities are even greater to do a better job in the future.

Conclusions

The selection and use of FORPLAN effectively met most if not all the technical, planning, and management criteria, especially as Version II was developed and implemented. FORPLAN provided an opportunity for uniform consistent analysis, yet allowed each forest planning team to adapt the model to their needs. It increased the opportunity to link RPA, Forest Plans, and the budget process. The planning needs of unit planning, timber harvest scheduling, and other resource objectives were pulled together in an integrated analysis. FORPLAN provided a basis for complying with NFMA requirements including the need for an interdisciplinary approach. It's use increased the analytical skills in the Forest Service and stimulated most resource specialists to increase their ability to quantify resource relationships and objectives. The decision to use FORPLAN will continue to provide benefits in the future. The benefits will be even greater if the Forest Service continues using it, because the initial costs and frustrations are well behind us and we can take advantage of all that has occurred.

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The Committee of Scientists Perspective on the Analytical Requirements for Forest Planning

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Abstract.--The analysis and documentation required in NFMA planning regulations can be classified into 24 generic categories. FORPLAN's capacity to meet analysis requirements at the forest level is very strong, particularly those related to timber harvest and activity scheduling, formulation of bench-marks and planning alternatives, and selection of vegetation management prescriptions. For 12 of the categories, FORPLAN can contribute, but must be coupled to other models or analytical procedures.

My assignment is to provide background on the legal and analytical requirements for forest planning on the National Forest System. I start by commenting on the work of the National Forest Management Act Committee of Scientists (COS), and follow with observations about alternative strategic approaches to planning. I then discuss the NFMA planning requirements in broad generic categories and assess, perhaps unwisely, FORPLAN's capacity to satisfy those requirements. I then conclude by asking, "Will comprehensive planning work?"

A disclaimer is in order; I am not speaking for the former COS. The discussion and analysis to follow reflects only my perspectives rather than those of my colleagues. However, the COS functioned with nearly complete unanimity regarding the implementing regulations for forest planning. I think the other members would agree with much of what I say here.

The Committee of Scientists

The COS was appointed to advise the Secretary of Agriculture on rules and regulations for implementing Section 6 of the National Forest Management Act of 1976. The Committee started its work in May, 1977, largely completed its duties in August, 1979, and was discharged by the Secretary following publication of the first rules in the *Federal Register* in September, 1979.

The COS was not a policy-making body. It's work was conducted in two related phases. First, we worked with Forest Service staff in preparing language to be considered for incorporation in the draft regulations. Congress probably envisioned a more reactive role us, but it turned out to be the only practical way to operate. Second, we evaluated and recommended changes in the draft regulations proposed by the Secretary. All 18 meetings were open to the public.

In late June, 1982, the former COS was recalled as consulting group for a three-day public meeting held in Washington, D.C. to give advice on the Reagan Administration's proposed revision of the NFMA regulations. The revisions involved substantive changes concerning regional plans, economic efficiency analysis, and management requirements for wildlife. Also, the rules, which were published in revised form on September 17, 1982 were reorganized, simplified, and clarified (USDA Forest Service 1982).

The seven COS members were drawn from the forestry schools and natural resource colleges. They were Art Cooper (North Carolina State U.), who served as Chairman; Thad Box (Utah State U.), Rodney Foil (Mississippi State U.); Ronald Stark (U. of Idaho); Earl Stone (Cornell U.); William Webb (New York State U. at Syracuse), and I.

The Committee was a multi- and interdisciplinary group. Six of the seven were biological scientists with experience in entomology, range ecology, soils, silviculture, wildlife, or forest ecology. I represented forestry economics, and was the only person with some experience in mathematical modeling of forest management problems. None of us were professional planners or system modelers. However, the duties of the COS did not involve either model specification or development, but rather the issues to be addressed, procedures, standards, monitoring, and documentation. It's task was to assure that the planning rules, guidelines, standards, and procedures rested on the best that scientific knowledge and an interdisciplinary point of view could offer at the time.

Then, and perhaps even now, two fundamentally different legal structures for planning were in a state of contention. One had a **prescriptive** orientation; it would define acceptable land-use and forest management practices by law. The second was **procedural**; it would establish planning requirements, procedures, and standards, but assign responsibility for decision-making to the judgment of resource professionals. With some exceptions, notably streamside protection and maximum size of clearcuts, NFMA largely adopted the procedural structure. The COS adopted the same philosophy; wherever NFMA permitted, it recommended process-oriented rules and guidelines for planning rather than prescriptions. Some critics thought the rules to be too process-oriented.

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However, we believed that NFMA and its legislative history mandated a process-oriented approach.

Planning Theory

There are two radically different models for planning and resource allocation on public land. The first, "incrementalism," would take existing land-use allocations, inputs and outputs, and programs as fixed and already sufficiently rationalized by the test of past experience. If adjustments are necessary, these can be considered on a site-by-site, case-by-case basis drawing on past experience in similar situations. Normally, only marginal adjustments need be made in each planning period, although the cumulative effect over time of such changes could significantly alter land-use allocations and practices.

The second model, "rational comprehensive" (Lindbloom 1959), in effect was adopted by congress in NFMA. The many, complex requirements of NFMA call for planning that is systematically comprehensive, and for decisions that are rationalized in terms of specific objectives and criteria. Thus the implementing regulations adopt a "zero-based" systematic planning procedure (Cortner and Schweitzer 1983) which:

1. Defines the objective or values to be maximized;
2. Identifies the full range of possible alternatives for achieving the desired objective(s);
3. Comprehensively evaluates the physical, environmental, social, and economic consequences of each alternative; and
4. Chooses the course of action which best realizes objectives.

Model Selection

The COS did not formally discuss or attempt to evaluate any specific modeling approach for implementing the analytical requirements of NFMA. The committee was aware of Norman Johnson's work to develop what eventually became FORPLAN (Johnson 1986), and it was intensively involved in constructing rules for timber harvest scheduling and development of silvicultural prescriptions. However, the decision of Associate Chief Douglas Leisz in December, 1979 to designate FORPLAN as the required analysis tool to be used for forest planning came after the Committee had finished its assignment.

I am reasonably confident that if the COS had considered the **generic** characteristics of the ideal analytical model it would have recommended the following key structural capabilities: (1) simultaneous multi-resource land allocation, activity scheduling, and prescription selection analysis; (2) analysis of both spatial and temporal allocation problems, including effect of predetermined policy constraints such as non-declining yield; (3) establishment and analysis of vertical linkages between forest, regional, and national level models; (4) establishment of horizontal linkages to other national forests and the private sector in a region; (5) economic efficiency analysis, including the establishment of cost-efficient alternatives; (6) economic and social impact analysis, including such things as impacts on employment, income, and changes in the distribution of benefits and costs; (7) documentation of analysis assumptions, standards, relationships, and data; and finally, (8) storage and retrieval of inventory data. In a moment, I will comment on FORPLAN's capacity to meet these and other analytical requirements.

John Russell (1986) has discussed why the Forest Service decided to develop an optimization model to satisfy these demanding analytical capabilities, and also the rationale for selecting MUSYC as the basis for developing what eventually became FORPLAN. NFMA and the implementing regulations require some form of mathematical modeling of the land management system to insure program feasibility, incorporate technical relationships, reflect resources availability, insure decisions are consistent with policy objectives and constraints, and for conducting trade-off analyses. Also, the model must have a capability for handling analyzing timber management programs, including temporal harvest scheduling, identification of suitable timberlands, rotation policy, and selection of appropriate silvicultural systems.

The COS regarded systematic analysis of timber issues as central to the planning process for three reasons. First, timber issues were central to the concerns that produced NFMA. Second, timber harvesting is the most important vegetation management activity that influences other outputs and resource values. Third, the Act contained more detailed, intensive requirements for timber than for any other resource. Thus, from my perspective, the already developed capabilities of MUSYC made it a logical choice for the new R&D work that would be necessary to meet the model specifications I have outlined.

FORPLAN and Planning Requirements

The analysis and documentation requirements stipulated in the NFMA planning regulations include several hundred different but often related items. Some were established in NFMA; others came in through the rule making process. It is impossible in the time available today to consider them all in detail. I assume that most of you are familiar with the NFMA regulations. I know that many of you have had experience in attempting to implement them in the planning process.

Table 1 lists the analytical requirements for forest planning in terms of a few generic categories. Another person might define these categories differently, and some overlap. Perhaps a few important items, such as mineral resources, have been left out. But I think the list captures most key analytical requirements of the NFMA regulations. Looked at another way, it provides a sort of check-off list for the development of analysis procedures and for the evaluation of simulation/optimization models that are used in support of planning and decisionmaking.

The first 19 items relate to analysis and planning at the forest level, while the others necessarily involve larger geographic units including possibly a region or whole state.

Table 1.--Analytical requirements for forest planning.

Requirements		FORPLAN Capability
1.	Interdisciplinarity	O
2.	Multi-resource coordinated planning	O
3.	Define resource production capabilities	..
4.	Establish benchmarks	..
5.	Alternative design and evaluation (trade-offs)	..
6.	Economic efficiency analysis	..
7.	Establish price/quantity demand functions	O
8.	Environmental impact analysis	O
9.	Meet management standards (constraints)	O
10.	Timber harvest and activity scheduling	..
11.	Establish vegetation management practices	..
12.	Identify land unsuitable for timber production	..
13.	Non-timber production/activity scheduling	..
14.	Potential Wilderness area evaluation	O
15.	Visual resource analysis	O
16.	Cultural/other resource interactions	O
17.	Analyze cumulative effects within a forest	O
18.	Inventory and information storage and retrieval	O
19.	Plan documentation	O
20.	Species diversity analysis	O
21.	Determine viable vertebrate population levels	X
22.	Economic impact analysis	O
23.	Federal/state/private coordination	X
24.	Analyze cumulative effects within a region	X

.. Independent potential capability to satisfy requirement.
0 Contributes but must be coupled with other models and/or analytical procedures.
X Not potentially capable.

Many requirements, particularly those related to timber, are highly specific and susceptible to quantification and analysis in an optimization framework. Others, such as those related to wildlife outputs, wilderness allocation, or recreation, are not as readily quantified or optimized. Two items, cumulative effects within a forest and across different forests within a region are not explicitly mentioned in NFA or the regulations; but I have included them both because cumulative effects have recently risen as issue in Idaho and because the requirement for federal/state/private coordination implicitly calls for analysis of cumulative impacts.

A simulation or optimizing model such as FORPLAN, creatively used by knowledgeable persons, provides a powerful tool for forest planning. However, the nature of the planning problem makes it unlikely than any single model will ever satisfy all the requirements. It is probably best to think of the planner/decision-maker as operating in an environment of several different models or processes. Some, such as FORPLAN or input-output models such as IMPLAN, will be quantitative and objective in nature, while others are qualitative and subjective.

FORPLAN's potential for meeting forest planning requirements depends on: (a) its inherent characteristics; (b) availability of data, and (c) the manner in which it is used. In Table 1, I have attempted a general assessment of Version 2's potential capacity **without regard to data availability or current practice**. Others, no doubt, will speak to those issues. The assessment is intended only as a framework for discussion. No doubt others will rate the criteria differently than I have.

FORPLAN is very strong in meeting analytical requirements at the forest level (items 1-19), particularly those relating to analysis of production capabilities, benchmarks, formulation of alternatives, timber harvest and activity scheduling, selection of vegetation management prescriptions (particularly those related to timber), non-timber activity scheduling, and economic efficiency analysis. This reflects its origins in RAM and MUSYC, and the susceptibility of modeling these elements in a linear, programming framework.

For many other key requirements, 12 or one-half of the generic categories, FORPLAN can contribute but must be coupled to other models or exogenous analytical procedures or processes. For example, FORPLAN has no inherent capacity for local or regional economic impact analysis, but its numerical results can be fed into an input-output model that can do that task. FORPLAN by itself cannot assure a balanced, interdisciplinary approach to forest planning, which is largely determined by the planning team's composition, perspective and political context. However, FORPLAN's analytical capacity for multi-resource coordinated planning and for trade-off analysis is consistent with the requirement for an interdisciplinary approach to planning

Similarly, FORPLAN version 1 allows for the specification of step-wise linear approximations of demand curves for timber, and version 2 for any output. However, as for timber yield functions, formulating the demand functions requires an independent analysis and modeling procedure. So far little attention has been given to the demand side of forest planning. Demand curves are usually represented in two step form: quantities up to the amount produced are assumed to be sold at a fixed average price, while quantities greater than that amount have zero value (Wilson 1986). In effect, it is assumed that price, whether market-determined or assigned, is invariant concerning the plan's outputs. This may be an appropriate assumption for a commodity such as timber, which is sold to a regional or national market, but not for recreation or wildlife which tend to valued by local or state level demand. In the future, more attention needs to be given to modeling the demand side of forest planning.

It would appear that in only three areas is FORPLAN in its present form incapable of meeting an analysis requirement: determination of viable vertebrate population levels; analysis of regional cumulative impacts; and federal/state/private coordination, including interactions between forests and between federal and private sectors.

The revised regulations expanded and clarified the analytical requirements for wildlife. To maintain viable populations of wildlife requires expressing threshold population levels in terms of habitat needs and management prescriptions. Such determinations must be made at least in part on a subjective basis outside of FORPLAN.

Once wildlife targets are quantified, FORPLAN can be used to simulate effects on other outputs and opportunity costs. However, FORPLAN has limited capacity for optimizing fish and wildlife population levels or species diversity. Both of these issues must be addressed at the forest and regional level, as illustrated by the case of the spotted owl in the Pacific Coast states.

Section 219.7 of the NFMA regulations calls for the Forest Service to "coordinate regional and forest planning with the equivalent and related planning efforts of other Federal agencies, State and local governments, and Indian tribes." The term "coordinate" would appear to imply some formal effort to integrate forest plans with the situation and objectives on other public and private land within the individual forest's area of influence, and to take account of the cumulative impact of all forest plans within a region or state.

Most states have not developed the necessary institutions or data base for coordinated planning, so the first forest plans have had to rely on informal, subjective, ad hoc processes. However, the California Department of Forestry's new Forest Resources Assessment and Analysis group is developing a state level data base, and models for analyzing the effects of alternative programs and policies on privately owned forest and range lands. The model will be linked to the 1985 national forest plans in California, offering the possibility of examining the impact of those plans at the state level. (Larry Davis will report on this project tomorrow). Also, Idaho has asked for an analysis of the cumulative effect of the new forest plans at the state level, and undoubtedly other states (including California and Oregon) with substantial national forest land will soon follow suit.

FORPLAN was designed to analyze resource allocation issues at the forest level. In the present form, it has no potential for integrated analysis or planning at regional or state levels, or for the examination of cumulative impacts. As these issues surface and take political form, as in Idaho, an R&D program to develop the necessary models and analysis procedures will be necessary.

Future planning on the national forests undoubtedly will move from its present largely exclusive emphasis on the individual forest unit toward integrated planning that formally recognizes linkages between the federal and private sector and cumulative impacts of federal actions on state economies. This is not to say there will be more centralized planning than now, but rather that there will be more emphasis on developing national forest plans that explicitly consider expected programs on other federal and private lands, and cumulative impacts on state economies and markets.

Will Comprehensive Planning Work?[2]

The NFMA planning and economic analysis requirements are numerous and complex. As pointed out by Cortner and Schweitzer (1983) the data required "are far beyond those ever compiled by the Forest Service or anyone else....". Some critics worry that the necessity for comprehensiveness, inadequate data, and imperfect methodology will inspire litigation to the extent that the whole planning system will breakdown.

Behan (1981) has even suggested that NFMA be repealed on grounds that this would eliminate the possibility of litigation, keep resource management out of the courtroom and refocus planning on "...the considered judgment of professional land managers.." rather than jumping through the hoops of the planning regulations.

However, it was litigation over timber harvesting practices on the Monongahela National Forest in *Issac Walton League versus Butz* that led Senator Humphrey to sponsor NFMA. Even without NFMA, an advocate with a smart lawyer will find some law to serve as a basis for litigation, as did the Issac Walton League. Further, even without NFMA, NEPA would require much the same planning process anyway. So the choice does not involve whether there should be a law, but rather how the law should be structured to foster the public interest in good management, rational decision making, and minimum interference by litigation.

I am much attracted to the NFMA procedural approach to planning for several reasons. First, it is the most democratic, because the key decision are made at the forest level where the interactions, trade-offs, and effects can best be evaluated by those who must carry out programs and bear the consequences. Second, it places great reliance on the skill, knowledge, and ethics of the professional resource planner. Third, with its emphasis on systematic, comprehensive problem-solving, it provides maximum opportunity for the application of economic efficiency analysis to the design of alternative plans and to the decision-making process.

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[2] This section is drawn nearly verbatim from Teeguarden (1985, p. 280-283).

If the NFA planning system doesn't work, it will be a major set back for the forestry profession, because a more prescriptive law surely will follow. In 1979, the COS warned that the process would be costly and imperfect. It also called for patience and cooperation in a continuous shared effort to improve data and analytical procedures.

The Forest Service has had good support as it has attempted to conduct the planning process under constantly changing edicts from Washington. Very soon, when the first round of NFMA plans is completed, there will be an opportunity to comprehensively evaluate how well the new system has done. That, in turn, will provide an opportunity to consider whether changes in the law or regulations are merited by the experience of planners, who had the formidable task of using imperfect planning arts to developed a technically sound, politically acceptable portrait of future resource management on the national forests.

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Technical Criteria Used in the Development and Implementation of FORPLAN, Version 1

Daniel B. Jones[1]

Abstract.--FORPLAN was influenced by modeling efforts in three areas: timber activity scheduling, area and unit planning, and transportation planning. A chronological summary is presented of some techniques and features of modeling and analysis which influenced the evolutionary development of FORPLAN. Computer and other considerations are briefly discussed and documentation is described.

The National Forest Management Act of 1976 was aimed at improving the Forest level planning process by reinforcing the principles of the Multiple-Use Act and requiring integrated planning by interdisciplinary teams. Passage of the Act created much interest in techniques that could solve the analytical problems implied in the law and regulations. For several years after it was enacted, there was considerable interest in evaluating existing analytical models and in developing new ones to help in planning.

Bill Russell just presented a discussion of the changing character of The National Forest management problem. Another excellent discussion of this and the technical evolution of analytical models developed for planning within the Forest Service, is presented in "The Genesis of FORPLAN: A Historical and Analytical Review of USDA Forest Service Planning Models" (Iverson and Alston 1986).

It is important to recognize that development was a dynamic process. FORPLAN provided a structure to build individual forest models, but innovative users found new ways to use the system and often identified problems and new techniques. As users encountered limitations, the developers attempted to solve their problems. As users gained experience and management got more involved, the process quickened.

To say that development was dynamic is probably an understatement. An expression used at the time was that using FORPLAN was like trying to ride a bicycle while it was being built. One never really knew what parts were there or whether they were working. An incident that comes to mind involves an analyst on one of the Forests. He was working late one night and gave me a call to report a problem with FORPLAN. I told him I would see if I could find the problem and call him back when I got it fixed. After I corrected the program I gave him a call. He had told me that he would be the only one left in the building; so, I should let the phone keep ringing until he could get to it. Well, I let the phone ring quite a long time, but he finally answered and said, "Hold on a minute. I was down the hall when I heard the phone ring, and I have to get my pants back on." To me that summarizes the development of FORPLAN-- we never had a chance to get our pants on.

Influences on FORPLAN

To understand the technical criteria used in the evolutionary development of FORPLAN, we first need to understand the important basic technical criteria in the models that influenced FORPLAN. If some of the terminology is not clear to the reader, the references for this paper and other papers presented at this symposium should provide the explanations needed to clarify it.

As Bill Russell described in his paper, the major development of planning models took place in 3 areas: (1) timber activity scheduling, (2) area and unit planning, and (3) transportation planning. FORPLAN's evolution was influenced by all three types of models.

Timber Activity Scheduling

FORPLAN's roots are deeply imbedded in two timber activity scheduling models: Timber Resource Allocation Method--RAM (Navon 1971) and the Multiple-Use Sustained-Yield resource scheduling Calculation, called MUSYC.[2] Timber RAM was used by most National Forests in the 1970's to help set their timber harvest levels and determine sustainability of harvest levels over time. Its use led to the acceptance of and reliance on linear programming (LP) as an analytical technique, at least in timber management.

In 1975, Johnson and others began work on MUSYC, in cooperation with the timber management staff. MUSYC was a linear programming-based approach designed to overcome structural and analytical limitations of Timber RAM while providing more land categories and constraints to help deal with clearcutting and land classification controversies that were surfacing (Johnson 1986),

With increasing pressure to control clearcutting, and to develop different management practices for different inventory categories, timber planners requested the ability to specify constraints that would reflect these emerging restrictions on timber harvest. To allow for this, the capability was provided to define each inventory category by three identifiers: working group, land class, and condition class. In addition, each possible treatment could be named by a treatment type. User-defined constraints were provided to enable restriction of the acres or volume treated by treatment type, by groups of identifiers, or forest-wide. Also, reports were provided for groups of inventory categories by treatment type, and for the acres in each age class per period. These inventory treatment type and age class distribution reports helped in interpreting the solutions and determining their effects.

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[1] Operations Research Analyst, USDA Forest Service, Eastern Region, Milwaukee, Wisconsin

[2] Johnson, K. Norman and Daniel B. Jones. 1979. Timber harvest scheduling model users' guide and operations manual [MUSYC]. Draft manuscript. 158 p.

Timber RAM, and to a great extent MUSYC, were used primarily to determine potential timber harvest volumes and determine sustainability of harvest levels over time. Other resources were not included explicitly in the models, but rather through timber yield adjustments and constraints on timber treatment. Effects on non-timber resources were inferred from the reports.

Area and Unit Planning

FORPLAN's development was also influenced by area and unit planning models, particularly the Resource Capability System (RCS) developed by the Watershed Systems Development Unit at Berkeley, California (1972). Iverson and Alston (1986) emphasize that the developers of RCS were among the leaders in the movement toward interdisciplinary team efforts at problem solving, and away from single-function planning approaches. RCS was a multi-resource model designed to simulate the response of on-the-ground resource analysis units to alternative management strategies. The RCS resource analysis areas were often the basis for classifying land use zones for unit planning purposes. A version of the system without response simulation models was created and called the Resource Allocation Analysis System (RAA).

Johnson (1986) points out that detailed timber activity scheduling was not emphasized in RAA and thus it did not fulfill the needs of timber management, including volume control. However, emphasis of RAA on equal treatment of multi-resource activities and outputs, the portrayal of yields as "timestreams," area control, and the concept of zones, or contiguous areas of the forest, were technical criteria recognized as being needed in FORPLAN.

Transportation Planning

The Integrated Resource Planning Model (IRPM) (Kirby et al. 1980) is another model that influenced development of FORPLAN. This model was developed by the Management Sciences Staff located at the Pacific Southwest Forest and Range Experiment Station. Johnson (1986) describes the model as being created through the merger of a Forest Service budgeting model with a road engineering transportation model.

Weintraub and Navon (1976) added some features to Timber RAM to explicitly consider construction of a transportation network with timber activity scheduling. This system was called Roading Timber RAM.[3]

The emphasis on spatial location of activities in IRPM and Roading Timber RAM was a concept incorporated into FORPLAN (Johnson 1986; Johnson and Crim[4]).

Chronological Development of FORPLAN

The following is a chronological discussion of the evolutionary development of FORPLAN Version 1, focusing on technical criteria. Describing the criteria chronologically should provide an evolutionary and technical perspective. The interpretation of events is my own, and others may have different interpretations, depending on their own perspective.

1978

The evolution from MUSYC to FORPLAN seemed very gradual to this author. If there was any single event that precipitated a change, it was the decision by Timber Management and Land Management Planning in fall 1978, to conduct a three month study to evaluate different ways to link allocation and scheduling models and thus address the dual problem of allocation and short term scheduling feasibility versus long term sustainability of timber harvest levels.[5,6] The purpose of this study was:

> "to develop and assess procedures which: (1) link resource allocation (land, capital, manpower) and output scheduling, and (2) result in an integrated forest plan that is feasible from an operational perspective. ... Since this study needs to be completed in a timely fashion...[it is] concerned with developing and assessing resource allocation and scheduling procedures on national forests where timber is a principal concern, and only linear programming procedures will be considered."

Four approaches to linking land allocation and output scheduling were proposed:

1. A two-part approach with static allocation and output scheduling models. The land allocation from the allocation model is used as input to the scheduling model. The schedule is thus dependent on the allocation, that is, allocation is pre-emptive.

2. A two-part approach linking an allocation and short term scheduling model with a long term timber harvest scheduling model to determine

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[3] Navon, Daniel I. 1980. Integrating timber and transportation planning. Draft manuscript. August, 1980.

[4] Johnson, K. Norman and Sarah A. Crim. 1980. Considerations of Roading in FORPLAN. Unpublished manuscript. September 15. 18 p.

[5] Crim, Sarah A. 1986. Personal communications, April, 1986.

[6] USDA Forest Service. 1978. Draft joint study proposal between Timber Management and Land Management Planning (untitled). 8 p.

sustainability of harvest levels. In the initial model, land allocations needed to meet alternative forest targets and output schedules for the RPA planning horizon are determined. The acreage allocation and short term schedule become input to Model II (MUSYC) where schedules could be refined and long term sustainability could be determined.

3. A one-part approach with explicit recognition of two "levels" of decision variables. Land allocations and output scheduling are done simultaneously. Each "level one" variable accounts for the proportion of each acre allocated that occurs within a particular timber stand grouping. These stand grouping acres are summed across analysis areas and made available to an appropriate set of "level two" variables. This eventually became the "aggregate emphasis" approach.
4. A one-part approach with one "level" of decision variables. This approach also arrives at a simultaneous allocation of land and schedule of output flows. It came to be called the "basic simultaneous" approach.

The issues to be addressed in the study were: (1) timing of output flows, (2) vicinity in allocation and scheduling, (3) objective function formulations, (4) operational feasibility, and (5) structural capability of each approach.

As part of this study, a steady-state allocation model was built for the Gospel Hump Study Area which also was modeled in MUSYC. Modifications to MUSYC were begun to provide linkages to the steady-state model. The study launched the FORPLAN development effort.

1979

During 1979 much of the basic structure of FORPLAN was developed. In the overview document for Version 1, Johnson (1986) states:

> "The Forest Planning Model (FORPLAN) was developed to provide an analytical structure which portrayed the multiple-use interactions that determine the range of choice in forest resource management. Classical timber harvest scheduling characteristics were retained to enable specification of efficient, sustainable schedules, but now within the broader context required by integrated planning. Starting with the basic analytical structure of MUSYC, improvements were made in how resources other than timber were represented and in definition of land areas. These improvements recognized: (1) choices other than harvesting and growing timber, (2) outputs other than timber, (3) values for outputs other than timber, (4) land other than commercial timberland, (5) geographic areas within the forest for reports and controls, and (6) geographic areas within the forest for allocation decisions (Johnson 1986)."

A 2-week training session for MUSYC was held in February, at Utah State University (USU). Johnson outlined the linkage study and some of the changes being considered for the system at that session. Tom Stuart, analyst on the Lolo National Forest, volunteered to participate in the project, using a large allocation model which would be linked to MUSYC via some common linkage rows. Acres allocated for timber production in the allocation model were transferred to the scheduling model through common linkage rows, where timber activities in MUSYC prescriptions were scheduled forest-wide.

Considerable discussion centered on the type of economic analysis that should be used in Forest Planning and the way costs and benefits should be portrayed in the model. In April 1979, John Sessions, economist for Timber Management, proposed the format for economic tables which were incorporated into the system.

On November 4, Johnson, Crim, and Jones[7] drafted a memorandum to Rex Hartgraves, Director of Land Management Planning suggesting

> "...an approach to resource allocation-output scheduling (RA-OS) for the accelerated planning forests that will complete their plans during 1980 and 1981. These forests were chosen in response to the President's directive to consider departure from the base timber harvest policy. Timber harvest scheduling is a significant issue on each and will form the core of their resource allocation-output scheduling problem."

The approach suggested in this memorandum had been named the Forest Planning Model (FORPLAN). The memo stated that FORPLAN includes..."MUSYC plus software linkages to various land allocation approaches that have been suggested and resource allocation matrix generators as they become available."

The memorandum became the basis for a letter addressed to Regional Foresters and National Forest System Staff Directors, and was signed on December 3, 1979, by Douglas Leisz, Associate Chief.[8] As Bill Russell described, the letter was written in response to requests that the Washington Office "make decisions on the analysis tools to be used" for forest planning. The letter directed: "The Forest Planning Model will be the required primary analysis tool for the Forest Plans." It also scheduled a technical review workshop with key Regional people for February 1980, and a user's manual and training session for FORPLAN during March.

Because the memorandum made FORPLAN the required primary analysis tool to be used in Forest Planning, further development was needed to accommodate the analytical needs of forests not included in the initial proposal.

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[7] USDA Forest Service. 1979a. Memorandum from K. Norman Johnson, Sara A. Crim, and Daniel B. Jones, to Rex Hartgraves, Director of LMP. (draft mimeo). November 4.

[8] USDA Forest Service. 1979b. Letter from Douglas R. Leisz, Associate Chief, to Regional Foresters and NFS Directors. 1920: Development and use of forest planning model. December 3.

1980

A technical review workshop was held in Fort Collins in January, with representatives from the Washington Office and several Forests. It was at this meeting that the naming conventions were agreed upon (e.g. MUSYC's "timber classes" were renamed "analysis areas," and "alternatives" were renamed "prescriptions," to be more consistent with planning terminology). It was determined that "management emphasis" identifiers in prescriptions would be the allocation identifier and could not change between existing and regenerated prescriptions. Thus land allocation could not change over time. A decision also was made that analysis area acreage constraints would be set as equalities, requiring every acre to be assigned a prescription. Thus every analysis area had to have a minimum intensity prescription available so that every acre would be accounted for in the solution, but cost efficiency still could be achieved.

In February, the first attempt at modeling the one-part approach with two levels of decision variables ("aggregate emphasis") was added to the model. This feature recognized geographic areas within the forest for allocation decisions, although its application was initially very limited.[5] This addition incorporated some of the principal features contained in the Lolo National Forest model.

In fall 1980, several important improvements were made to FORPLAN:

1. Vegetative type conversion was difficult to explicitly model, so the ability was added to change from one working group in existing vegetation to another in regenerated vegetation.
2. Innovative users were augmenting FORPLAN matrices with their own to model some relationships not permitted in FORPLAN. They needed the ability to generate balance equations to serve as transfer rows for linking their matrices with FORPLAN matrices. The ability to specify constraint levels equal to zero was added to provide this capability. An example of this is a set of constraints which limits valuation of a resource to its estimated consumption level even if produced above that level.
3. Users needed a way to constrain on combinations of identifiers as a single constraint, for example, on several conifer types, as a group, to provide for minimum winter cover requirements for wildlife. "Composite" constraints were structured to provide this flexibility in constraining on combinations of identifiers. This permitted the identifiers of any number of mutually exclusive FORPLAN constraints to be combined into a single constraint.

1981

During this year the Forest Service assumed responsibility for maintenance, user support, and further development of the model from the developers.

In February, the ability to generate "free" rows was introduced. Because Version 1 never could generate more than one objective function at one time, this feature permitted any constraint to be used as the optimization criterion. It also allowed for a full set of constraints to be generated, but used selectively in later solution runs, reducing the number of times the matrix generator might be run.

In fall, the option of defining intervals spanning several time periods was added for scheduled output constraints. This had the potential to reduce the size and density of matrices by grouping time periods in these constraints. This allowed period-specific constraints in the early periods and broader interval-specific constraints over the later periods, where time resolution was not as critical.

1982

As more users began to use the system, additional needs emerged:

1. In the initial formulation of FORPLAN scheduled outputs were modeled as being dependent on the age of analysis areas or type of timber activity that was prescribed. Periodic yield types were added to permit scheduled outputs to be modeled independently from timber activity or age. This feature was an important step in improving the multi-resource capabilities of FORPLAN.
2. The President's revised Statement of Policy for the Forest and Rangeland Renewable Resources Planning Act (RPA) which was sent to Congress in January, 1980, included the policy that "the productivity of suitable forested land, in all ownerships, should be maintained and enhanced to minimize the inflationary impacts of wood product prices on the domestic economy and permit a net export of forest products by the year 2030." To help forests respond to this policy, the ability to optimize and constrain timber growth was added to FORPLAN.
3. As users became more sophisticated and management desired better ways to constrain certain activities, the types of scheduled output constraints was greatly expanded. This permitted greater flexibility and more accurate representation of the management strategies being modeled.
4. Enhancements to FORPLAN always progressed at a greater rate in the matrix generator than in the report writer. As a result, even though modeling improvements were made, it was sometimes difficult to interpret results until the report writer was enhanced. In 1982, major improvements were made in reports, including more economic reports, and more selective reporting by analysis area level identifiers.

Computer Considerations

A discussion of technical criteria in the development of FORPLAN would not be complete without some discussion of computer hardware and software.

Although FORPLAN source code was in the public domain it did not receive wide dissemination outside the Forest Service for two reasons: it was in a constant state of revision and the source code was very system-specific to Univac. The first reason is obvious when the rapid nature of the development effort is considered. The second reason is not so obvious.

Although much of the programming was done on Burroughs and Vax computers at Utah State University, modifications and production was being done on Univac at USDA Fort Collins Computer Center (FCCC). Because of Univac software limitations and the architecture of the hardware itself, many of the input/output routines and storage conventions had to be modified to reduce cost and storage requirements. This resulted in a set of code which is not easily transferable from Univac.

On January 23, 1981, Norm Johnson sent a letter to Director of Land Management Planning, Rex Hartgraves, about FORPLAN analysis costs).[9] Johnson had conducted some tests which showed that FCCC costs were 2-4 times greater than USU costs. He suggested an effort be made either to bring FCCC FORPLAN costs down or to relocate the FORPLAN use site. In response to the first suggestion, cost algorithms at FCCC were revised and efforts increased to improve the efficiency of FORPLAN on Univac. Testing FORPLAN on other sites was considered and tested on a limited basis, but the problems associated with communications and support prohibited implementation of this option.

Impacts on Fort Collins Computer Center were significant. Special procedures were required to schedule FORPLAN runs to minimize impacts on the system. This often resulted in long delays and frustrations for the users. Expansion of the computing facilities seemed to lag behind user needs.

There were a few conversions of FORPLAN to other computer systems. Conversions required a great amount of time and expense. Boise Cascade Corporation had one of the most intensive efforts and successes in conversion. Some of the applications on other computer systems are discussed elsewhere in these proceedings.

Other Considerations

Dick Field[10] played a major role in providing the goal programming feature in MUSYC and FORPLAN. His graduate work on goal programming at The University of Georgia was conducted with Timber RAM and he proposed its inclusion in MUSYC and FORPLAN. His critique led to improvements in the formulation.

Univac, vendor of the computer in use at the Fort Collins Computer Center, recognized the Forest Service as a major user of it's Functional Mathematical Programming System (FMPS) linear programming package. This is the system which solves for the optimal solution of the matrix generated by FORPLAN. Univac helped Land Management Planning to make more efficient use of the system and make enhancements which took advantage of the unique structure of FORPLAN matrices. The results were greater efficiency in solution time (reduced costs) and greater flexibility for the user.

Documentation

Formal documentation has always lagged well behind development. Although drafted in 1980 (Johnson et al. 1980), the User's Guide was not published in final version until May, 1986 (Kelly et al. 1986). Other documentation consists of an Overview (Johnson 1986), Mathematical Programmer's Guide (Kent et al. 1985), and Structures and Options Guide (Johnson and Crim 1986).

Because formal documentation was very limited and slow in being developed, the primary means of communicating with users has been through informal ways. Conference systems on the FCCC Univac, accessible by all Forest Service users, were the primary source of new information. Unfortunately, information in these conferences was not readily available to interested parties outside the Forest Service. However, final documentation cited above incorporates much of the material that was contained in these informal sources. Other informal documentation was distributed through personal networks.

Conclusion

The decision for all National Forests to use a single model as the primary analysis tool to develop Forest Land and Resource Management Plans permitted a national pool of talented and innovative people to influence development of that model. Although not explicitly referenced in this paper, many people had a role in testing and enhancing FORPLAN. Challenges they presented, innovative ideas they provided, and endless testing they conducted were an important part of the development work.

The untiring efforts of Norm Johnson, Sarah Crim, and others counted largely in the success of FORPLAN. Without such dedication and commitment, development could not have moved as quickly and effectively as it did.

Successful application of a system such as FORPLAN requires a central contact and maintenance facility. Full time, proficient help always has been available for FORPLAN users. Without such help most users would have given up in frustration or made only token use of the system.

FORPLAN Version 1 made some significant inroads in incorporating multiple resource allocation and output scheduling. It was continually expanded and modified to meet the analytical needs of users. Eventually, however, the basic framework of Version 1 could no longer efficiently accommodate needed changes, and efforts were channeled into a new version. The evolution of Version 2 is discussed in Reuben Weisz's paper.

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[9] Utah State University. 1981. Letter from K. Norman Johnson to Rex Hartgraves, Director of LMP. Subject: Cost of FORPLAN analysis. January 23.

[10] Field, Richard C. 1979. Some comments and suggestions regarding MUSYC and goal programming. Personal communication, May 3. 7 p.

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Technical Criteria Used in the Development and Implementation of Version 2 of FORPLAN

Reuben Weisz[1]

Abstract.--Version 2 of FORPLAN was designed to provide the user with flexibility in model formulation. To achieve this goal, 14 technical criteria were used to guide its development and implementation.

Dan Jones has described the development of Version 1 of FORPLAN. FORPLAN continued to evolve as its strengths and weaknesses were recognized.

An objective of FORPLAN has been to make it understandable to a wide range of audiences including people inside the Forest Service and people from other organizations and interests. FORPLAN evolved in much the same way that human understanding evolves, i.e., the evolution of understanding takes place by analogy. Each new idea is comprehended in terms of how it resembles old ideas. As old ideas are tested, the weaknesses become criteria for the growth and development of new ideas. The criteria guiding the development of Version 2 evolved from recognition of weaknesses in Version 1 and from renewed emphasis on some of the criteria used in developing Version 1.

For discussion, it is useful to divide the criteria for evolution into those that guided the evolution of the initial formulation of Version 2 and those additional criteria that also guided the evolution of later releases.

Criteria for the First Release

As we began on Version 2 of FORPLAN, there were eight criteria guiding the model development effort:

1. FORPLAN should be meaningful to our potentially affected interest groups, to line officers, and to members of the interdisciplinary teams that were most directly involved in land management planning.

If FORPLAN meets this criterion, an interested person can comprehend the input data for the model and the results produced by FORPLAN. An interested person can understand what the input and results mean for each specific land area, each specific management emphasis, and for the forest as a whole.

A major problem with Version 1 was that the procedure for developing input data was too complex for persons without extensive computer or analytical experience to understand. The outputs were scattered through many pages and a complete prescription of a given land area was difficult to assemble. If the data input procedures were less complex, those reviewing the model and its results would be less likely to be overwhelmed by them and would provide more active participation in the planning process.

2. A simple spreadsheet-like input data format should exist.

Concerns for input simplicity lead to a simple input data format called Direct Entry FORPLAN or DE FORPLAN. In contrast with the input conventions for Version 1, Directly Entered data placed all information about one prescription in one location in the data set. This made it easier to review the activities and outputs associated with a prescription. Bringing all the information together in one spot helped satisfy the first criterion--the model must be understandable.

The input format adopted for the first release closely resembled the input format used by a software package called ADVENT. Because Forest Service people had considerable experience using ADVENT in the budgeting process, the Version 2 Direct Entry format replaced what appeared in Version 1 to be a strange, new, complicated program with something resembling a familiar software package. ADVENT was the analogy needed to transform the strange into the commonplace, thus again achieving the first criterion--the model must be meaningful.

In addition, Directly Entered data simplified the analysis of spatial problems, which are addressed further in Criterion 3.

3. The model should allow different types of land organization to be represented in the analysis.

One of the major decisions to be made in planning is determining which practices or activities, and standards and guidelines are to be applied to each type of land area. Each type of land area included in FORPLAN is called an analysis area. The types of analysis that can take place in FORPLAN are in part defined by how the analysis areas are defined.

Because Version 1 evolved from the tradition of timber harvest scheduling models, it had a strata-based approach to defining analysis areas. In this approach, analysis areas were homogeneous, noncontiguous pieces of land; for example, "ponderosa pine, mature sawtimber, less than forty percent slopes." Homogeneous, noncontiguous analysis areas simplified the work of some resource specialists who needed to estimate yield coefficients for FORPLAN. The simplification resulted because the same type of yield, or environmental effect, could be assumed to occur on the same type of land because of the same type of management action wherever that type of land occurred. However, compiling input data for the mixed resources on a given land area became difficult because the input data were scattered throughout the data set and were not aggregated for the entire land area. Comprehending the computer printouts for a spatially contiguous land area became difficult, because the results were disjointed--i.e., scattered throughout the report.

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Version 2 allows the user to enter data for (1) homogeneous, noncontiguous analysis areas; (2) heterogeneous, contiguous analysis areas; or (3) a combination of homogeneous and heterogeneous analysis areas. Some examples of a contiguous analysis area are a roadless area, a watershed, or a transportation analysis zone. The ability to provide input data for heterogeneous contiguous analysis areas is important because many planning issues are related to a specific geographic area on a forest. Managers need information to make decisions about specific contiguous areas of land.

4. The model should include all outputs, activities, yields and costs for each analysis area.

Version 1 had a limited number of activities and outputs. Besides timber, there were 10 scheduled outputs; these were either timber outputs or other outputs driven primarily by timber harvest schedules. Also, there were ten nonscheduled outputs; nonscheduled outputs tended to reflect the management emphasis or other non-changing attribute associated with a prescription. Also included in the model were eleven timber cost categories which were a function of either the acreage or output of timber harvested. While the dominance of timber concerns in the input data was logical for a model that evolved to meet the needs of timber harvest scheduling problems on significant timber forests, it made modeling nontimber activities and outputs difficult on forests (or analysis areas) where timber harvest concerns are less critical.

Version 2 allows the user to specify up to 200 activities and outputs but none of the activities and outputs are mandated. Those items tracked can be custom defined according to the needs of the analysis allowing such items as "jojoba beans" or "cave recreation visitor days" to be tracked if such outputs are relevant to resolving issues.

The ability to track a large number of items made it possible for more people interested in the land management plan to have items tracked in the model. Increased participation in the planning process occurs because the model becomes more meaningful to more people, thus again helping to satisfy the first criterion. Tracking more activities and outputs also helped attain the other criteria of Version 2 which follow.

5. FORPLAN should be compatible with the Forest Service accounting system.

The Forest Service has a standard set of naming conventions that are used to account for its activities (actions) and outputs (the results of those actions). These accounting codes are used at all levels of the organization (local, regional and national) for many types of analyses (project planning, program planning, national assessments, etc.)

Version 1 used an alternative and more limited set of naming conventions that were based on timber terminology. Such usage created problems for the users because it required a disaggregation or translation of the Version 1 conventions into the standard conventions before the data was useful. Version 2 solves this problem by allowing the user to use both standard data definitions and custom defined names, and by allowing the user to incorporate several activities and outputs into FORPLAN.

6. FORPLAN should not be biased towards a specific function of the Forest Service.

Because Version 1 had evolved from a timber management model it was best suited for analyzing the timber resource. However, the analysis of other resources was forced to take place within the conceptual framework of a timber harvest scheduling model. From a practical standpoint, the analyst and interdisciplinary team members often felt they were trying to put square pegs into round holes. Feelings of mistrust were perpetuated among those planning participants and observers who were concerned that timber activities received primary consideration during planning operations.

For example, Version 1 required at least one timber yield table in order for the model to run. This was only a minor problem in the code, but a major irritant to users having concerns with the plan's credibility.

Version 2 can be run with or without timber yield tables, because it does not force a particular functional emphasis on the model. Such operational ability makes it easier to do integrated resource analysis.

7. FORPLAN should allow costs to be expressed as a function of activities that take place on the ground.

Version 1 required that costs fall into one of two categories: (1) Timber Costs, and (2) Other Resource Costs. The latter were costs per unit of output, and the timing of the output was mostly influenced by the timber harvest schedule.

Version 2 allows the user to define costs per unit of either activity or output, and allows costs for any resource to be independent of timber activities. Costs may be defined as "cost per acre," "cost per area," "cost per mile of road," etc. This is a more straightforward and logical way of representing costs.

8. FORPLAN should not limit the number of consequences that are considered for a given resource.

Version 1 allowed 99 yield tables for each scheduled output. The yield table showed the yield per acre of a resource. Theoretically, if a forest had a hundred unique analysis areas and each analysis area had ten alternative management emphases, there could be up to 1000 (1000 = 100 * 10) unique sets of yield per acre values. However, these results had to be averaged into 99 unique yield tables.

Averaging of values could make the model less responsive to the way that alternative prescriptions would affect selected issues and concerns.

Directly Entered data in Version 2 was not limited to this restriction.

Additional Criteria for Later Releases

At first glance, the first release appeared to have everything that an analysis would require. It allowed defining the planning model in real world terms and doing so in a simple and straightforward manner. Only one problem remained. The initial release required a massive amount of input data and produced a massive amount of output. The analysis process was smothered in information. The following additional criteria were added to guide the evolution of software development.

9. FORPLAN should minimize the amount of input data required.

The first release used simple and straightforward input data procedures. However, the data sets could easily range from 200,000 to 2,500,000 records in size because of the necessity to repeat data. Therefore, this method increased the (1) costs of creating input data, (2) likelihood of undetected errors, (3) difficulty in debugging detected errors, and (4) increased the computational burden on the computer.

Later releases of Version 2 solved this problem by minimizing the amount of data that needed to be repeated by using a variety of modeling techniques such as "yield tables, yield composites, theming, coordinated allocation zones," etc. One very useful technique gave the user the ability to create multiple timing choices for the scheduling of a prescription. For a detailed description of these techniques, please see the references that are contained in the references to this paper.

As an example of how to avoid repeating data by using a relationship, consider the formula, $Y = 2X$; the value of Y equals twice the value of X.

Contrast this simple formula with a data set that contained all possible values of X and Y:

X = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, etc.
Y = 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, etc.

The simple relationships give the same information in a clear and concise manner.

Another advantage of using relationships is that they are easier to change than are the numbers that result from those relationships. Using the above example, if an interdisciplinary team examined the relationship $Y = 2X$ and determined that it should be $Y = 3X$, this would require a simple edit--changing "2" to "3." In contrast, with the first release of Version 2, one would have to change

Y = 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, etc. to
Y = 3, 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, etc.

Using a small set of explicit relationships instead of a large data set also helped reformulate the model. Planning involves a constant need to reformulate the model to respond to changing needs for new analyses. With a data set from the first release, reformulating the model often required weeks or months of work, whereas in later releases the same effect can be accomplished in minutes.

10. FORPLAN should custom tailor the reports to meet the needs of the users.

The first release produced so much computer printout that the user was overwhelmed by information. The user's printer was often tied up in printing lengthy reports that no one had the time to read.

Later releases allowed the user to custom tailor the reports by choosing one of two methods so that only desired information was reported. This was accomplished by two means. The first was an optional reporting system in FORPLAN that allowed the user to custom tailor the reports to the needs of the analysis. The second was called the "flat file capability." The flat file is a data set containing FORPLAN results that can be downloaded from the Fort Collins Computer Center to the user's Data General minicomputer. The user could then define and custom tailor reports by utilizing the Data General "Present" report writing software.

11. FORPLAN should include a transportation analysis capability.

Version 1 of FORPLAN allowed the analysis to portray resource flows across time, especially the timber harvest scheduling problem.

Version 2 of FORPLAN also allows the analysis to represent resource flows across space; this capability is most commonly described as the "network formulation" or "transportation analysis capability." It is useful for identifying the best mix of resource projects and the corresponding best road network for a particular area. Analysts can use the transportation analysis capability to more accurately represent road costs and transportation considerations. Because road costs represent such a significant proportion of the total costs of forest management, this feature allows a better job of economic analysis to be done.

12. FORPLAN should allow the consideration of multiple outcomes in an analysis.

Models constructed using Version 1 of FORPLAN were based on an assumption of certainty. If a specific management emphasis was selected in an analysis area, then a specific sequence of timber growth and harvest scheduling events was assumed to take place. Random events which generated catastrophes or affect successional stages, such as pest infestations and the occurrence of fires, provided multiple outcomes which were either ignored or accounted for through reduced yields.

Version 2 has a "Model II" capability which allows the analysis to explicitly consider "multiple outcomes"; for example, when fire occurs, portions of stands are killed and set back to age zero while other parts continue to grow. Model II allows the analysis to more accurately depict the uncertainty associated with forest dynamics that are a consequence of random events.

13. FORPLAN should give the user the best usable information for the dollars spent on computer computations.

Early in the planning process, it became obvious that generating and solving large FORPLAN models was expensive and time consuming. An underlying criterion which guided all development and enhancement work was to make FORPLAN models as inexpensive as possible to create and solve. A variety of strategies such as "multiple objective functions, generalized upper bounds, tolerances for linear programming coefficients, scaling matrices, year groups between rotations," etc., were adopted and succeeded in reducing the cost and time involved in making FORPLAN computer runs.

14. FORPLAN should be a "white box."

This is a restatement of the first criterion; that is, FORPLAN should be understandable. It seemed necessary to restate this criterion, because the first release in some respects turned out to be a "black box" because it was not readily possible to sit down and read through a data set that contained from one-half million to 2.5 million records. The volume of records produced also reduced our ability to debug the model and to do quality control of the input data.

Later releases of FORPLAN more closely resemble a "white box." The goal of a white box is to produce a process which is easy to use and easy to understand. As FORPLAN progressed toward "white box" status, significant changes in input procedures and output results occurred.

Reducing the size of a data set by substituting shorthand relationships for the data that resulted from those relationships improved both understanding and communications among all the participants in the planning process. By explicitly displaying relationships used to generate the FORPLAN model, each user can understand how data are generated and combined with other data to form the FORPLAN model. Understanding helps quality control and the interdisciplinary process and increases participation by managers, specialists, and other interested parties.

The simplification of FORPLAN produced the ability to print out all the activities and outputs associated with one or more timing choices of any prescription. Giving the user the ability to view in one place all the yields, costs, benefits, and activities associated with a prescription allows the user to better assess whether the items that were modeled were being correctly portrayed in the model. This again helps quality control, the interdisciplinary process, and increased participation by managers, specialists, and other interested parties. Thus, as FORPLAN grew, it simplified inputting the resource data, assessing data under various circumstances, and reporting the results to the user.

Conclusions

The latest release of Version 2 of FORPLAN combines the best features of Version 1 of FORPLAN with the best features of the first release of Version 2. Many additional software techniques have been added as well. The criteria used to guide the technical evolution of Version 2 of FORPLAN resulted in a state of the art system for land management planning that satisfies analysis needs.

Version 2 gives simple and streamlined procedures for formulating meaningful FORPLAN models. The software is general and flexible enough to meet most needs for analysis that have been defined by users in this round of planning.

If one had to state one criterion which incorporates most of the other criteria discussed in this paper, it is this: **FORPLAN should allow flexibility in model formulation**. Forest planning models are ways of thinking about problems. A model is a good model if it describes the world accurately and the way the user sees it. Version 2 of FORPLAN is general and flexible enough to allow the user to view the world this way.

By meeting the criteria set out for Version 2, the developers of FORPLAN have created a product that can be used for plan development and implementation. It is hoped that in a few years, we can meet again at a workshop entitled, "FORPLAN: An Evaluation of a Forest Plan Implementation Tool."

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Evaluation of the Use of FORPLAN in Management Planning on the Shoshone National Forest

Stephen P. Mealey[1]

Abstract.--Congress' major intent for U.S. Forest Service planning was to reduce conflict and improve the quality of resource decisionmaking. The Shoshone National Forest Plan, based on FORPLAN II analysis, established management intent and disclosed effects of management at the Forest and sub-district (10,000- to 40,000-acre) levels. This approach reduced conflict, improved conflict resolution and improved the quality of decisions and management. Examples are discussed in terms of localized management intent, increased management efficiency and improved budgeting. The Shoshone's Plan reduces uncertainty and creates an improved environment for intelligent risk taking.

Reviews of the legislative histories of the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) and the National Forest Management Act of 1976 (NFMA) and the resource management concerns of Senator Humphrey reveal preoccupations with conflict between members of the forestry, conservation and environmental communities. To reduce conflict and improve the quality of natural resource management decisions, Humphrey's and Congress' intent, as expressed in NFMA, was a planning process which set long- and short-term goals and objectives based on interdisciplinary team effort and a high level of public involvement.

Implementation of the Shoshone National Forest Land and Resource Management Plan began April 14, 1986. Analysis for the plan was completed in Version II of FORPLAN. Analysis areas (fig. 1) were small "contiguous, non-homogeneous" units ranging from 10,000-40,000 acres. As a result, effects of proposed actions were disclosed on a site-specific basis. More important, the plan established the Forest's management intent for the next 10 years for each of 109 geographically-distinct areas.

On June 23, 1986, a trial was held in the U.S. District Court for the State of Wyoming. Plaintiff was Park County (Wyoming) Resource Council, et. al., and defendant was the BLM with Snyder Oil Company intervener. Plaintiff sought a temporary restraining order barring the drilling of an exploratory oil well on the South Fork Shoshone River, Shoshone National Forest. They claimed, among other things, that the Environmental Assessment (EA) prepared by the Shoshone National Forest failed to consider certain alternatives and, therefore, violated the provisions of the National Environmental Policy Act (NEPA). Judge Kerr's June 25, 1986 findings, in part, follow (points of emphasis are added):

> With respect to the merits of this case, the Court finds that the federal government's review of the Snyder lease and drilling proposal was extensive. First, the **Federal Government examined the Shoshone National Forest plan** and the South Fork Oil and Gas Leasing EA, documents that had been completed within days of Snyder's filing the Application for Permit to Drill (APD) and that **discussed oil and gas operations in the very area in question**. Second, the federal government prepared a "scoping" document to outline other matters that should be considered in an additional environmental analysis it planned to prepare. That scoping statement was sent to over 300 individuals and organizations, including plaintiffs. Based on the 31 written comments received on the scoping statement, the federal government prepared an EA on the Snyder APD. That EA discussed four alternatives -- the no action alternative, approval of the proposal with stipulations, approval of an APD with an alternate road alignment, and approval of an APD with stipulations limiting activities in the fall. Based on that analysis, the federal government concluded that the proposal would not have a significant effect on the environment and issued the APD on May 30, 1986.
>
> The **Court has examined** the EA prepared for the Snyder APD and **the Shoshone National Forest plan and the South Fork oil and gas leasing EA that it incorporates**. The Court concludes that these documents fully address the matter and that the federal government's conclusion that the proposal will not significantly affect the environment is reasonable. The evidence demonstrates that **the Federal Government took the required "hard look" at the environmental consequences** of the proposal and reasonably concluded that the proposal should be approved.

During the trial I was asked by Richard Stacy, U.S. Attorney, to define my major role in the matter as

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[1] Forest Supervisor, Shoshone National Forest

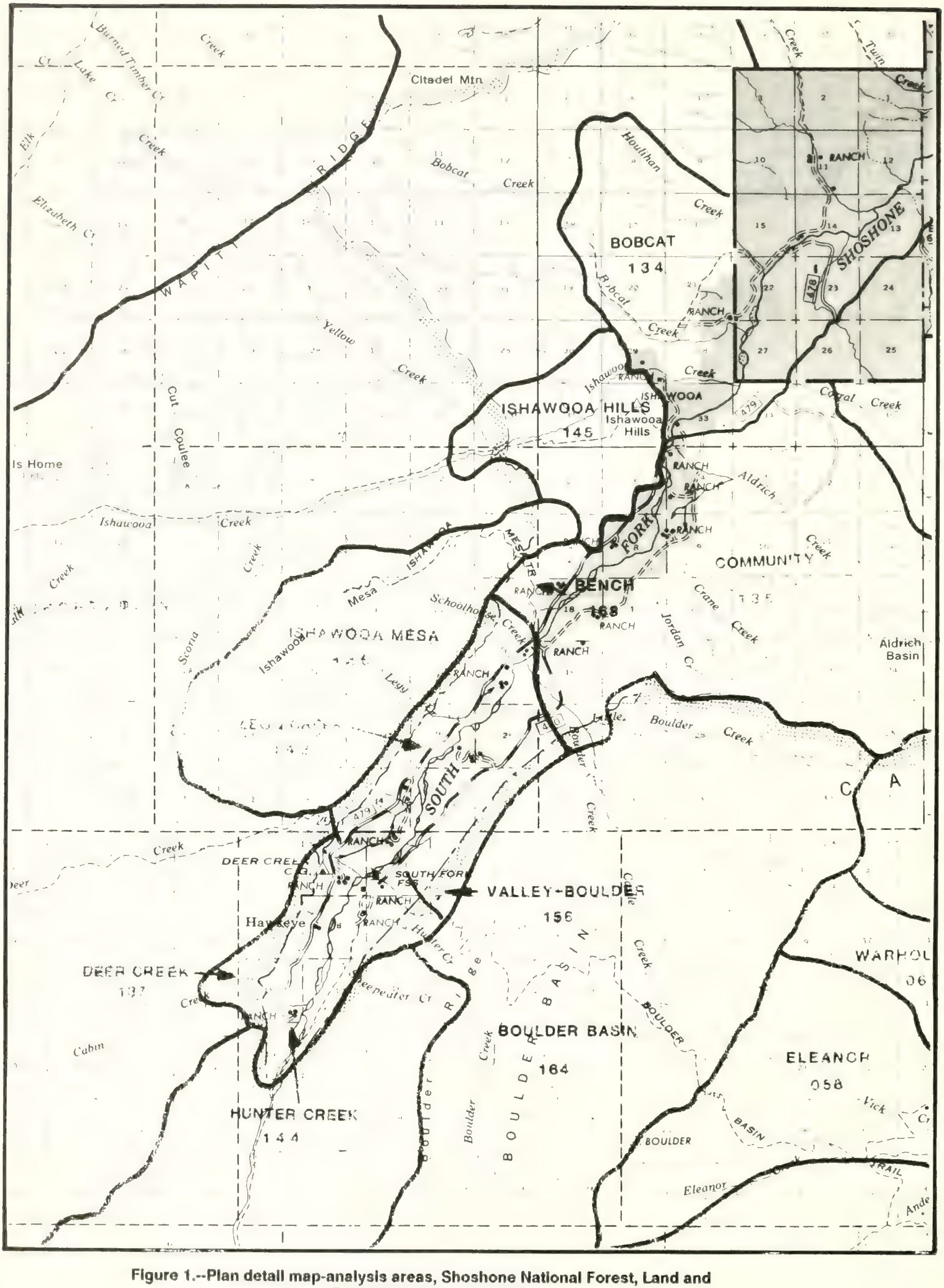

Figure 1.--Plan detail map-analysis areas, Shoshone National Forest, Land and Resource Management Plan.

Shoshone Forest Supervisor. My response: "To select an alternative from the EA prepared for the Snyder Oil APD which most closely followed the Forest's intent for the area as established in the Shoshone National Forest Plan, and recommend the appropriate action to the BLM."

Results

Judge Kerr's June 26, 1986 Decision and 6 months of informal evaluation of the implemented Shoshone Plan against Congress' expectations of forest planning, permit my belief: **The Shoshone plan has reduced conflict, improved conflict resolution, and has significantly improved the quality of decisions and management**; these trends will likely continue. This belief is supported by three examples of major results of the area-specific analysis and decision making done in Forplan II.

Localized Management Intent

Management (FORPLAN) prescriptions in the Shoshone planning model represent alternative ways of addressing issues, concerns and opportunities on small, geographically-distinct areas. The Plan represents a set of management practices selected and scheduled for each of 109 analysis areas, each area having its distinct and unique direction. Because plan development dealt with local issues on recognizable areas and the final plan states clearly the management intent in constituents' "favorite back 40s," most Forest and local issues have been resolved. A specific conflict resolution process was employed in the development of the "preferred alternative" (Appendix F, FEIS) to assure a focus on issues at both levels. A low number of Draft Plan responses (186) was interpreted to mean that the broad and local planning and issue resolution approach was effective. There were seven appeals of the Plan and five interveners. Two have been resolved, and five are pending. The legal challenge which has occurred (Park County vs BLM) was resolved swiftly and decisively because local management intent is clear in the Plan and proper tiering had occurred. Finally, because management intent in the Plan is clear at the local level, public uncertainty about future direction is reduced allowing public dialogue to shift from "what should be done" to "how to do it." The result should be better ground-level management.

Increased Management Efficiency

On July 1, 1985, Clarence Brimmer, U.S. District Court Judge for the State of Wyoming, denied a motion for a temporary restraining order sought by the Park County Resource Council to stop Marathon Oil Company from drilling an exploratory oil well on the North Fork of the Shoshone River, Shoshone National Forest. Plaintiffs contended that the Environmental Impact Statement (EIS) issued for the drill site was inadequate because it did not take into account the entire lease area, and that if the drilling were allowed, the environment would be irreparably harmed. In denying the motion, Judge Brimmer stated "especially since a thorough job was done by both the U.S. Forest Service and the BLM in issuing the drill site EIS, the Court is hard-pressed to see how plaintiffs can ultimately prove that these agencies failed to comply with NEPA."

In 1985 and 1986, the Shoshone Forest faced legal challenges from the same plaintiff over exploratory gas and oil drilling in two similar but different locations. The Court found for the Forest in both cases. However, there was a major difference. In 1985, lacking a Forest Plan, sufficient NEPA compliance required that the Forest participate in the preparation of two draft EIS's and a final EIS at a cost of $133,000. In 1986, with a Forest Plan, sufficient NEPA compliance required only a brief EA tiered to the Plan, completed at a cost of $10,000.

Efficiency in a general sense means doing more at less cost. In 1986, a completed Forest Plan meant a critical minerals management job, with National implications, could be completed adequately at 92.5% less cost than a similar job in 1985.

Improved Budgeting

Budget development often is an agonizing and time-consuming effort involving collecting data about funding needs on Districts, analyzing needs, presenting budget options and choosing among options. Ideally this involves a complete analysis of each project in terms of financial benefits and costs, multiple-use benefits and costs and environmental, social and economic impacts. Information is reviewed for all projects, and a budget is developed that meets constrained budget levels and maximizes net public benefits. Before Forest Plans, this ideal was rarely achieved, primarily because necessary information on projects was lacking and a suitable mechanism for competitively examining all possible projects was unavailable.

On the Shoshone National Forest, as shown, FORPLAN II was used in a site-specific manner. One of the features of FORPLAN II is that the full set of report information can be translated onto a form compatible with the decision-based software on the Data General (DG) computers. This means that much of the information necessary for analysis of potential projects is readily accessible through use of generalized report writers and programs, such as Spread Sheet.

The level of analysis done as part of Forest Planning on the Shoshone, when combined with accessibility of information, answers many of the difficult questions involved in budget development. The mix of projects and intents necessary for maximizing net public benefit is complete. Information on practices to be applied by distinct geographic areas is available. This information, when meshed with tentative budget levels, is ready for analysis and decision making. The important result is an efficiently-developed budget directly linked to and accurately reflecting the intent of a site-specific plan.

Conclusion

In most situations, an inverse relationship between risk and uncertainty is apparent. That is, low risks seem appropriate when uncertainty is high, while greater risks seem appropriate when uncertainty is reduced. In today's management climate, with increased issue complexity and reduced budgets and staff, managers are encouraged to accept greater risks in management and decision making. Intelligent risk taking can occur only when the degree of uncertainty is known. The Shoshone's Plan, with analysis and management direction at both Forest and local levels, reduces uncertainty about management intent and creates an improved environment for intelligent risk taking.

Use of FORPLAN in Management Planning on National Forests

Orville Daniels[1]

Abstract.--Managers and decisionmakers encounter new management challenges when using complex planning models. They must assemble an analysis team made up of unfamiliar skills, manage the process carefully, and be prepared to use the results appropriately. Managed well, such models can be a positive decision tool.

The Forest Service has just completed a massive 6-year use of the planning model, FORPLAN. While the advantages and disadvantages of FORPLAN modeling for resource land management decisionmaking are being debated and explored by professional planners, little attention is being given to the management implications. The past 6 years have shown that few general managers are trained or experienced in organizing for, directing, and interpreting complex optimization modeling. The purpose of this paper is to explore management concepts for the manager who has decided to incorporate modeling into their decisionmaking process.

FORPLAN use to plan for large land masses is costly and requires much management attention. These costs include computer time, staff salary, and delay in the decision process. You can expect that starting with data base formulation and moving through to a legally supported conclusion may take more than 1 year and cost about $200,000. Also, considering the potential for serious mistakes means that the manager should not start the process if he or she is unwilling to devote the resources and attention to do it well.

First, most units will need to create an analysis team which will increase the size or alter the makeup of the organization. Operations research, economics, and Forest planning skills, and a team of resource specialists, will be needed. It is essential that they be at or above the journeyman level. Skimping can be disastrous. Seldom does operations research and economic skills encompassed in the same person work as well as with two people. Generally it is better to have part-time separate skills rather than combine them. The synergism is worth the cost, and there is normally not enough time available for one person to do the job. The bottom line is a core team of well trained, experienced, technical people supported by a wider pool of resource specialists.

Second, with the team in place, a management climate and atmosphere must be established. This too is very important. Creativity, curiosity, and identification with the mission of the planning effort is critical. Choosing people who display these characteristics is important, as is maintaining a climate in which these attributes are encouraged. Use your best management skills to develop trust and personal responsibility. Establish that this is a staff function being done for you, the decisionmaker. Show its importance by your involvement, by expressing your management needs and vision, and by taking the results seriously. Early demonstration maximizes payoffs. On our Forest, we eliminated timber sales from our program early in analysis because of indicated problems. The team was strongly motivated by that display of the importance of their work.

The manager should be willing to devote considerable personal time to the process. Your involvement not only motivates the team, but constant involvement reduces committee compromises. Compromises by the team are not as acceptable as a decision by the manager after the team has done the trade-off analysis. At one point, our team was considering solutions where sensitivity analysis showed $1,000/AUM shadow price for elk and we directed them back to a less costly solution. Keeping track of such items calls for periodic briefings and accessibility. The team knew they could contact me at any time to resolve problems. It was also important to be available at critical times during the analysis, even if that was Saturday morning.

Managers need not understand the details, but should understand the concepts being used to handle the major resource issues. Issues such as sediment production, timber growth and yield, and wildlife cover needs are often greatly affected by the methods used in modeling. The manager should know and control which methods are used. After all, the model must be consistent with the manager's view of the world. If not, one or the other must change.

There are some pitfalls possible, including coefficient development, the black box syndrome, and impatience.

Coefficient development, such as timber yield tables, unit costs, and resource coefficients, are the foundation of the model. Give your people as much time and encouragement as possible to do this job well. Some of your people may have to spend considerable time updating themselves in their profession before they ever start with the coefficients. Encourage it. We found that the confidence people had in the coefficients made them strong ambassadors for the plan during implementation.

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The black box syndrome is a fear, suspicion, and overdependence on the machine. A good analysis team should be able, after a little experience, to fully explain the results of model runs and predict outcomes of various proposed changes between runs. When this ability is developed, the black box syndrome begins to dissipate and eventually the whole team can develop a more 3 realistic expectation from the model. Be aware that a manager can add to the black box syndrome by his or her own fear, suspicion, or overdependence. Instead, ask questions and mentally compare results with what you know about the land. Learn the key variables and know what is not quantified in the model. In other words, give leadership to the analysis.

Impatience is natural in this process, but needs to be curbed. This is a complex, large, and new process. Accept that things will not go as smoothly as planned and that errors will be made regardless of how hard people try. If a hard punishing accountability approach is followed, creativity, curiosity, and risk taking will suffer; the product will be diminished, and the schedules are likely to be missed. Or worse, errors may exist that are not found by your team, but surface after you have published your results. Try to help the team solve problems, rather than add to stress by a witch hunt. They already will be stressed by the delays if you have helped them be committed.

A fourth pitfall is a lack of vision or understanding of how you will implement, monitor, and evaluate the final plan. By having a clear vision of these three steps, you can give better leadership to the planning process and aid the analysis team through the details. You may have to constantly remind people of the product resulting from the planning effort.

The use of FORPLAN may sound too difficult to manage. I hope not. It is a challenge, but not an excessive one, and the results are well worth the effort.

Panelist Discussion of FORPLAN Evaluation Papers: Session I

D. L. DeAngelis[1]

Abstract.--This discussion considers a few basic issues involved with FORPLAN for the point of view of its adequacy as a model framework. These issues are (1) the optimization approach, (2) linearity of models, (3) spatial resolution, and (4) uncertainty.

My comments are those of an outsider to management and planning modeling, but one who has worked in mathematical and computer simulation modeling for the past 15 years. I believe that an outsider without preconceptions can bring some useful perspectives to reviewing FORPLAN.

As a modeler who focuses primarily on the basic research aspects of ecological systems, in reading and hearing the papers presented on FORPLAN I was impressed that the development and use of management models is as intellectually challenging a problem as that of developing and using more research-oriented models.

The scientific and management aspects of our interest in ecological systems are not greatly different. Underlying our study of these systems is a desire to make them work better to serve our needs and, also preserve certain intrinsic values in such systems. The use of mathematical models is a way to help achieve these ends.

In these comments, rather than reviewing individually the papers on the agenda in Session I, I will try to address some of the main issues involving the adequacy of FORPLAN as I see them. A major point I wish to make is that the creators and users of FORPLAN are dealing with some of the same problems and concerns that modelers in the ecological sciences are encountering. For this reason, I want to make a bit of a digression to outline my subjective view of the connections between management models and research models.

Research Models and Management Models

I am using the term "research model" in a somewhat restricted way to refer to models used mainly for scientific rather than management ends. This is an oversimplification, because management models such as FORPLAN can be used both in a research mode and for planning.

Models normally used in research might be classified into three general categories: (1) descriptive models, (2) heuristic models, and (3) predictive models. Descriptive models merely try to fit some sort of mathematical relationship to observed behavior. Regression models fitted to data points are of this type. Heuristic models are attempts to explain or understand a phenomenon by describing it in terms of more basic mechanisms. For example, the Lotka-Volterra equations are a heuristic model that attempts to explain oscillatory behavior of biological populations. Predictive models are designed to forecast future behavior of a system. (A predictive model may be very good at prediction without being based on a correct understanding of the system, as the Ptolemaic model of the planetary motion exemplifies.)

Most models used by research ecologists are mixtures of descriptive, heuristic, and predictive aspects, rather than being purely of one type. However, I would estimate that heuristic and descriptive aspects dominate over predictive aspects in most ecological models. Some ecologists are unhappy over this state of affairs. Peters (1980) has stated that "the making and testing of predictions is the necessary and sufficient condition for all science." He asserted that ecology will not become a "mature" science (in the sense that physics is, for example) until a predictive body of developed. I believe that limited predictive capability is present in some areas of ecology, but accurate prediction is still a far-off goal.

A final comment about research models is that operationally, if they deal with dynamic systems they usually employ differential or difference equations or some variations of these.

How do management models relate to research models? Because they are used to project the possible future results of alternative management strategies, they are similar to predictive research models. A management model must incorporate some form of predictive model. This may be in the form of explicit differential or difference equations, or it may be implicit, through the derivation of model coefficients by other, predictive models. However, management models such as FORPLAN also differ from research models in important ways, because they contain two additional components:

1. An objective function, which measures something the management program is trying to optimize;

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2. Constraints, which limit the allowable behaviors of the system based on human decisions.

It is in the addition of these two components that management models such as FORPLAN diverge from models used in research. Because of this management models have to be judged, in part at least, by different criteria than research models. The objective function and constraints embody economic and societal values, the evaluation of which is outside the range of science.

Aside from the objective function and constraints, however, the management model is a predictive model. It simply turns around the question, "What will happen to the system under certain conditions?" to, "How do we impose a strategy of activities to get the system to behave in the best way for our needs?" Thus, models for the management of natural resources must rely ultimately on predictive models from biology and ecology.

As stated earlier, the present capacity of ecological models to make predictions is generally low. This necessarily imposes limitations on the effectiveness of management models that rely on ecological information. I am sure that users of FORPLAN are aware of this, but I believe the problem of predictive uncertainty in ecological systems needs reiteration.

One point of this digression has been to call attention to the close relationship of research and management modeling, and it leads to the corollaries that the users of natural resource management models must be well acquainted with the state-of-the-art in ecological research modeling and that research ecologists can make a contribution towards improving the ecological components of management models. Another point has been to stress the uncertainty in most current models. In the next section, I will discuss the problem of uncertainty in more detail, along with three other issues that I think are important to discuss in relation to FORPLAN.

Some General Issues Related to the FORPLAN Model

There are four general issues concerning the FORPLAN modeling approach that seem important ones to me. These issues all relate to the applicability of this approach to complex ecological systems. I will first list these issues and then discuss them separately:

1. The use of economic optimization models in dealing with ecological criteria;
2. The linear structure of the FORPLAN approach;
3. The degree of spatial resolution in FORPLAN;
4. The uncertainties in model parameters going into FORPLAN.

Issue 1. Optimization

The approach taken is to combine decision variables additively into an objective function, which is then optimized. The creates problems, as is well-known, because market and non-market values have to be combined; that is, values such as wilderness and habitat preservation have to be expressed in the same currency as timber and grazing values. If this currency is in dollars, as it seems to be almost always in FORPLAN, the latter values are likely to overwhelm the former ones.

It is true that environmental values can be safeguarded by applying appropriate constraints, which FORPLAN has special flexibility in doing because of its spatial explicitness (discussed below). Still, the utilitarian bias implicit in the optimization approach seems to ensure that the intrinsic values such as species diversity and landscape aesthetics will get less emphasis. These values may be maintained, but not optimized.

One possible alternative approach would be to develop another economic objective function besides the type now used, one based purely on ecological values. These functions could be optimized separately and then a "bargaining" process between the advocates of the utilitarian objective function and the advocates of the ecological objective function could be undertaken. A particular objective function might combine species diversity, the welfare of certain selected species, and some landscape factors. There are ways of quantitatively ranking such values in importance through methods such as the analytic hierarchy approach (Saaty 1980). This quantitative ordering could be used to construct an ecological objective function. Environmental advocacy groups could be invited to do this.

Issue 2. Linear Model Structure

FORPLAN is a linear programming approach, which means that the objective function and constraints are linear functions of the decision variables. In principle, the coefficients of the objective function and constraints can be computed even if the underlying predictive model describing a dynamic system is nonlinear. However, this is only an accurate approximation if the nonlinearity is mild enough to allow piece-wise linearization.

There has been a history of debate in ecology about whether linear models are able to describe ecological systems in an approximate way. However, today very few ecologists would deny that ecological systems are nonlinear. These systems are characterized by sharp jumps in variable values (e.g., population levels) at thresholds, rather than continuous behavior. For example, a portion of habitat (or archipelago of habitat islands) of a given size may be able to support a sizable population of a particular species, but if the size is made only slightly smaller, it is possible that no population will be maintained. This sort of phenomenon, related to mathematical catastrophe theory, is common in highly nonlinear ecological systems.

For these reasons, when criteria such as the maintenance of certain wildlife populations are required, there is some question about how reliable linear models are. It may be that clever use of constraint inequalities can get around this problem to some extent in FORPLAN, but this will require the use of detailed population models as input to FORPLAN to estimate what the constraints must be to maintain species populations.

Issue 3. Level of Spatial Resolution

The types of options that can be included in an optimization model depend on, among other things, the level of spatial resolution in the model. In this respect, there has been considerable progress over the years in the development of FORPLAN.

It may be interesting to compare some trends in ecological theory with similar trends occurring during the same time period in National Forest model development. Early models of interacting ecological populations, such as the Lotka-Volterra equations, ignored spatial extent and heterogeneity. In the early 1970s, theoretical ecologists (e.g., Horn and MacArthur 1972) attempted to deal with landscape heterogeneities by considering the landscape to consist of fractions of different landscape types, each of which could be occupied to some fractional extent by different species. Explicit spatial relations between portions of habitat were not included. Starting in about the middle 1970s, with work by Levin (1974) and others, a further elaboration on the inclusion of spatial characteristics was begun. These models reflected the view that relative spatial positions of habitat areas of various types are important, not just the fractions of the landscape covered by the types.

With explicit spatial models of ecological systems, theoretical ecologists can study both the spatial dynamics of ecological communities, and the temporal dynamics. Important aspects of spatial dynamics include such things as faunal dispersal, the persistence of populations on sets of noncontiguous habitat patches, and the spread of pests and other disturbances.

In the models leading up to FORPLAN, there has been a similar type of progression from very simple models that ignore space to those in which spatial aspects are explicit and detailed. In particular, the steps from Timber RAM to FORPLAN involve, in simple terms, the following spatial properties.

1. Timber RAM. This is a harvesting model with a specified number of timber classes. Although these timber classes refer implicitly to areas of land, no spatial heterogeneity or explicit spatial relationships are included in the model.

2. MUSYC. This model approach allows, among other things, a variety of treatment types, with constraints on area or volume treated by a particular treatment type. Thus, there is spatial heterogeneity, though the explicit spatial patterning of this heterogeneity is not incorporated in the model.

3. FORPLAN. Explicit spatial heterogeneity and geographic location are incorporated in the model by defining a set of zones.

I do not think the degree of spatial resolution in FORPLAN is capable at this point of dealing with many of the important ecological spatial aspects mentioned earlier. However, in a gross sense, FORPLAN permits the recognition of landscape heterogeneity and makes it possible to treat land areas with high significance to wildlife in a special way. There is potential for increased spatial application in the future if necessary.

Issue 4. Uncertainty

As mentioned earlier in this paper, uncertainty is present in all ecological systems, whether managed or not. Even if all initial conditions in such a system could be measured perfectly, unpredictable random disturbances, such as unusual weather, fires, or pest outbreaks, can occur. These produce uncertainty even in well understood relations such as timber yield functions, but can produce enormous uncertainties in other biological components of ecosystems. This is because effects of disturbances are often amplified in ecological systems. Besides being subjected to random disturbances, ecosystems can also undergo long-term continuous changes caused by slow changes in exogenous parameters such as climate or by cumulative effects of human-caused influences such as acidic deposition.

The consequences of this uncertainty in system behavior is that the coefficients of the objective function and constraints in FORPLAN are necessarily highly uncertain. The FORPLAN approach, however, is deterministic. Only the means of the coefficients are included in the analysis, not the variances, which would be large if known. The problem with this is that the analysis will compute only the most likely outcome of a particular management strategy, not the risk of undesirable outcomes.

My feeling is that the structure of FORPLAN allows the inclusion of uncertainty, but only with difficulty. It should be mentioned that there are other management optimization models that include uncertainty, though these models are much smaller than FORPLAN models. An example is a model for the reduction of phosphorus loading to a lake (Bogardi et al. 1981). In this model several alternative measures are considered that may be taken to reduce P loading, each of which would cost a certain amount of money and have a certain expected effect. Besides the mean expected effect of each measure, the variance was also included in the model, reflecting the uncertainty inherent in the efficacy of the measure due to random effects. The results of the model are expressed in terms of a probability distribution of possible total effects on P loading for the best strategy, so that both the risk and the likely result of poor performance can be seen.

Given the large size of most FORPLAN models, I doubt that the uncertainty can easily be handled in any thorough manner in the fashion of the above example. The variances of hundreds of parameters would have to be known, and A Monte Carlo simulation of absolutely gigantic proportions would have to be carried out. Nonetheless, it may be feasible to do some sensitivity analysis on a small set of parameters that are perceived to be crucial. For example, the probability of satisfying a particular ecological constraint, such as the maintenance of an endangered species population, could be computed in relation to an optimal strategy by including uncertainties in species dynamic behavior. If the risk to the population under this strategy is perceived to be too high, a suboptimal strategy that reduces the risk might be preferred.

I believe that the FORPLAN approach should have the capacity to select suboptimal strategies when they sufficiently reduce the risk of an undesirable outcome. I suspect that in actual practice, this sort of mode of FORPLAN usage is already possible to some degree. Mealy (these proceedings) reported that FORPLAN has helped avoid high risks by recognizing situations with high uncertainty in outcomes.

I have commented only on uncertainty arising from the general impossibility to predict accurately the behavior of ecological systems. There are other sources of uncertainty, simply because, in models of any kind, there can be a variety of types of error, including programming and simple transcription and typing errors in preparing input information. All modelers who have worked at their trade for very long have at some point reached the sobering realization that big models inevitably contain errors. The size of FORPLAN models makes it difficult to do enough experimental runs to ferret out errors of this sort. It is advisable that techniques be used to minimize the probability of error occurrence.

Conclusions

In summary, it is difficult not to be highly impressed with the quality of thought that has gone into the FORPLAN approach and with the excellence of the personnel involved in developing and using it. It is easy to point to some of FORPLAN's problems and limitations, as I have done, but any other approach would have as many or more difficulties. Also, I like the idea of there being a single modeling structure, such as FORPLAN, rather than a chaos of different approaches for each administrative unit. Despite the effort required to understand it, the net effect of FORPLAN seems to be to focus thinking and promote communication. Given the flexibility of the FORPLAN framework, and the ingenuity of its users, I believe that most of the issues I have raised (and probably other issues as well) can be dealt with adequately.

My comments are intended to be constructive. Some are doubtless naive and cover well-worn ground, but I believe they may represent those of an outsider who has had only a few weeks to become familiar with FORPLAN. I hope that, as such, these comments will be helpful in the evaluation of FORPLAN.

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Reflections on the Development of FORPLAN

K. Norman Johnson[1]

Abstract.--The Forest Planning Model (FORPLAN) is discussed in terms of its uses in national forest planning, why it remains a mystery to people inside and outside the Forest Service, and its role in completing the national forest plans. Predictions are made about future developments in the forest planning methodology and suggestions are made about the limits of analysis in solving forest planning problems.

The Need for FORPLAN

FORPLAN has gained a significant role in national forest planning for three reasons:

1. It was available when the national forests wanted a forest planning model, and it deals with the two major themes that have been at the center of forest planning: (a) the scheduling of timber harvests within constraints, and (b) the pursuit of cost effectiveness.
2. It helped break the hold of professional omnipotence on national forest management planning.
3. It helps shield the Forest Service from attacks by its critics.

Being at the Right Place at the Right Time

National forests primarily build roads and cut timber. Most national forest planning has addressed timber management and road management scheduling. Therefore, the National Forest Management Act (NFMA) addresses the control of these action more than any others. The Act is very one-sided in its treatment; almost all the attention is focused on timber management scheduling.

It is not surprising that the national forests turned to a model that has its roots in timber management scheduling. As documented by Iverson and Alston (1986), FORPLAN descended from a long line of timber management scheduling models.

Models may appear to be abstract and sterile calculation procedures; but they really are embodiments of the philosophy and ways of thinking about problems of the people who build them. FORPLAN is no different.

To foresters, the heart of forestry is the birth, growth, and death of trees, stands and forests. Further, to foresters, the important issues in forest planning relate to active manipulation of the forest, and such planning should focus on what timber harvest levels can be sustained over time, given the objectives and constraints from all forest uses. FORPLAN reflects this orientation in its long time horizon, long planning periods within this horizon, and use of vegetation age and rotation length as organizing principles that focus on issues across time instead of space. Such an orientation is compatible with the emphasis in NFMA, but takes the focus on traditional forestry perspectives far beyond their emphasis in that Act.

Economists are interested in objective-oriented problem formulations, the finding of efficient solutions, and the related perspective of finding a maximum or minimum subject to constraints. FORPLAN also reflects this orientation with its optimization (linear programming) approach to problem solution, use of a present net worth objective function, and focus on delineation of a wide range of choice. It is more difficult to find justification for this economic approach in NFMA than the focus on timber management. While the Act mentions that efficiency should be considered, it is not emphasized. A much stronger focus is the assurance of protection of the forest environment during all actions.

Selection of an optimization model for forest planning has limited the ability to consider environmental effects in detail in forest planning modeling. I do not believe that an optimization model such as FORPLAN is required by the NFMA. An equally strong argument can be made for models that emphasized the simulation of environmental effects from road building and timber harvesting. Some "efficiency" might be given up; but the ability to estimate environmental effects might be increased.

The focus on optimization models resulted from three separate threads of development that became intertwined: (1) my continued development of timber scheduling models based on the work of Daniel Navon, who introduced harvest scheduling with linear programming to the national forests (Navon, 1971); (2) the fascination of land management planning with linear programming as expressed through the development of the Resource Capability System (Betters 1978); and (3) the focus of the Committee of Scientists, under the leadership of Dennis Teeguarden, on economic efficiency and trade-off analysis.

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To my knowledge, a comprehensive evaluation of optimization vs. simulation models never occurred before the selection of FORPLAN as the primary analysis tool, despite the importance of that decision. By default, the national forests chose the pursuit of economic efficiency in their forest planning model over the detailed simulation of environmental effects, with much of that simulation either left to secondary models, or left out.

With the rewrite of the regulations in 1982, the fusion of timber management scheduling and economic optimization became complete. In fact, the regulations now read, in large part, like the work of a Ph.D. student in forest economics. The "greatest good for the greatest number in the long run has been recast as "net public benefit." Benchmarks that require maximums and minimums have been added and economic terminology has been inserted whenever plain English appears about to surface.

Whatever the process of legitimization and development, forest planning as we know it and FORPLAN appear inseparable. It is true that FORPLAN was built to serve forest planning, and also that the national forests use FORPLAN's capabilities and limitations to mold and defend what is done in forest planning. The claim that "FORPLAN cannot handle it" has become a well-worn reason for not representing an aspect of forest planning of interest to someone.

Even the public must deal with FORPLAN. Continual references to it occur in presentations of Forest Service personnel and in draft forest plans. Also, constructing a comprehensive alternative to a proposed forest plan requires that the information be processed through FORPLAN. To many people, FORPLAN symbolizes forest planning more than any other aspect of the planning process.

Quantitative Analysis as Protection Against Professional Omnipotence

My Ph.D. thesis focused on the evaluation of alternatives for a roadless area in the Coast Range of Oregon. Although it was light on quantitative analysis, it did build a simple harvest scheduling model to simulate the harvest of the Siuslaw National Forest, with and without the timber from the roadless area. Out of this thesis have come the two major interests in my professional life: (1) the multiple-use, sustained yield problem on national forest lands; and (2) timber management scheduling as the heart of forest planning.

My first major modeling effort occurred in the context of an analysis of future timber availability from Oregon's forest lands that culminated in the "Beuter Report" (Beuter et al. 1976). Lynn Scheurman and I built the TREES model to do the projections on timber availability, with Lynn handling the mechanics of model building and I providing the ideas on what it was to accomplish. That model has had a long life. It and its progeny, such as TRIM (Tedder 1986) are still in wide use.

About that time John Walker began pushing his ECHO model at the national forests (Walker 1976). We had put the ECHO option into the TREES model, and Region 6's Timber Management staff asked me to use it in a study on national forest timber harvest levels.

In that analysis, I looked at national forest scheduling results based on Timber RAM and noticed some peculiarities that RAM was causing. Over about 2 months, I built a harvest scheduling system that overcame these difficulties and presented the results to a collection of National Forest System personnel in Portland. Using these results as a springboard, I began to work with the National Forest System build a model, called MUSYC, to replace Timber RAM.

After completing MUSYC, I returned to policy analysis. However, the Roadless Area-Intensive Management Study (Fight et al. 1979) brought me back to modeling. Using the Willamette National Forest's own planning model (a traditional timber management planning model), we showed the Forest that the harvest level could be maintained without accessing the roadless areas by intensive timber management on the accessible land. Forest personnel were unimpressed. They said that their planning model ignored so many constraints from resource objectives besides timber that the model did not accurately reflect the benefits and costs of different timber management plans. Rather, they substituted their own qualitative judgment for the model results to a significant degree.

While no model completely reflects reality, their forest planning model was so far off as to be largely irrelevant. They had used it to understand better how much timber management investment would be needed to maintain the harvest, but were not interested in its results beyond that.

If the Forest did not believe its own forest planning model, it would be of little use for policy analysis. This triggered the search for a model that could incorporate constraints and objectives for resources beyond timber production, and led to the building of both FORPLAN Version 1 and FORPLAN Version 2.

In one sense that search has succeeded too well. Now the Willamette N.F. must use the exact allowable sale quantity (ASQ) from the FORPLAN run for the preferred alternative as the ASQ in the Forest Plan. Constraints and objectives from other resources now must be represented in the forest planning model to have an effect on ASQ. While the result helps surface the assumptions of the planners, it is still a source of concern that it drives out the intuitive and nonquantifiable aspects of this analysis.

Planning models are valuable to planners and decision-makers to the degree that they allow these people to think through their problems. These are not predictive models of what will happen in the future. The data is too scant for that. Rather, they organize the objectives, constraints and assumptions of the people using the model to help them understand the implications of their proposals--to help them answer the what-if questions as they search for solutions to planning problems. These models are not meant to dominate the process or drive out aspects of the thinking by planners or decision-makers that cannot be quantified.

Such reliance on models shows a lack of faith in the judgment of resource professionals. Lack of trust in the Forest Service by outside interest groups and citizens has led to more demands for justification for each action. This, in turn, has led to the demand for "objective" analysis, which seems to result in quantitative analysis.

FORPLAN fills that need. It is one tool in an internal cleansing of the professional beliefs and tenets that have guided national forest management from its inception. It is part of the attempt to prevent professional groups within the Forest Service, especially foresters, from imposing their objectives for management of the forest on the rest of society. But in the process, the qualitative judgment of resource professionals may be lost.

Protecting the Forest Service from its Enemies

FORPLAN also is a formidable roadblock to gaining leverage to push the national forests in any direction other than the one they wish to go. The complexity and subtleties of its options, the comprehensiveness of its view, the incredibly ambitious task given to it by the national forests, and the tremendous variance in its use from forest to forest makes it difficult to understand it and its use.

Yet, analytical attempts to disagree with the national forests must often deal with it. Few outside the Forest Service have figured out how to do that. Without the knowledge of FORTRAN's intricacies, fear exists that (1) those on the outside will not understand the key analytical pressure points that control the solution and, therefore, will not know what are the key assumptions behind the harvest levels; and (2) even if they could figure out the key assumptions, the national forests could reconstrain the model to obtain the same answer.

Thus FORPLAN is very effective at preserving local agency discretion. It represents a formidable way for the national forests to insulate themselves from their critics.

Why Is FORPLAN Such A Mystery?

FORPLAN remains almost as much a mystery to most people in the Forest Service as 8 years ago. It certainly remains a mystery to people outside the Forest Service.

I have outlined below six reasons for this phenomenon: (1) FORPLAN's inherent complexity, (2) lack of publication about it in scientific journals, (3) lack of in-depth analysis of its results, (4) separation of the people with forest planning problems from people analyzing these problems, (5) the counter-intuitive way FORPLAN represents problems, and (6) lack of the model's availability to outsiders. Also, I suggest some remedial action.

First, FORPLAN remains a mystery because of its inherent complexity. Starting with the Committee of Scientists and going right on through to the building of FORPLAN, we have developed a forest planning process that may go beyond the average planning team's ability to implement. Involvement of university scientists in forest planning has enabled these faculty to try out their ideas on planning in the largest field laboratory ever utilized--the National Forest System. Combined with the Forest Service's can-do attitude, the work of these scientists may have resulted in a planning procedure beyond the ability of ordinary people to complete successfully.

Although we tried to write FORPLAN so that it would be understandable to potential users we may have misjudged our clients. We probably wrote it for the most analytically sophisticated of the planning teams rather than the average. This orientation, combined with the mobility of Forest Service employees, has meant that the average planning team may feel befuddled by FORPLAN.

Second, FORPLAN remains a mystery because its methodologies and use have not been published in the scientific literature. The development of national forest planning methodologies has proceeded outside the organized research community. New ideas were developed and directly implemented in national forest planning without the publication and peer review basic to the research process. The aggregate emphasis-coordinated allocation approach to forest planning is an example. This approach is used throughout Region 6; yet, it has never appeared in the scientific literature.

The National Forest System does not encourage publication of findings by its people, in contrast to the Forest Service Research branch. Publication takes time and energy away from other activities. Thus, much of FORPLAN and its procedures is passed along among managers and planners. In all the criticism I have heard of FORPLAN within the National Forest System, lack of publication in the scientific literature has not been one of the complaints.

Third, FORPLAN is a mystery because many of its practitioners don't understand it. Traveling to the national forests around Oregon and around the country, it is discouraging to see how little time is spent understanding why particular FORPLAN results are being found on each forest.

Certainly the "benchmark analysis" added to the revision of the regulations in 1982 ensures that at least a mechanical set of trade-off analysis will be done. The numbers from these results also can lend themselves to being summed to regional totals. But this approach to developing the choices also drives out creative analysis by focusing on a set number of runs.

Planning teams could do more FORPLAN analysis than the benchmarks; but there is rarely any time for that. Reliance on the creativity of the analyst, which had some successes and some failures, often has given way to lock-step mediocrity. A "FORPLAN analysis" now often means doing a benchmark run and surfacing a few summary numbers. Digging into the details of the results to understand "why" things are happening occurs less often.

The long time between the analysis and plan release compounds the problem. The person who did the analysis often is not on the job anymore.

FORPLAN training also has contributed to seeing forest planning as a mechanical procedure. The training sessions have been concentrated on organizing the input and creating the output needed to do a FORPLAN analysis. They have focused on what the options are and what the reports mean. They have not concentrated on how to integrate the information produced by FORPLAN to understand the key factors determining the results. Without this understanding, though, we remain outsiders seeing changes happening from run to run without understanding why.

Fourth, FORPLAN remains a mystery because of the separation of analysis from the people who needed it to solve their problems. Good planning models are extensions of the thinking of the people for whom they are intended. With the addition of the "operations research analyst" as the specialist on the planning team, we have created a position for a professional modeler. The advantages of this approach are that the analysis can be done more quickly and in a more sophisticated fashion. The disadvantage is that no one besides the "analyst" may know how they are representing their forest planning problems in FORPLAN. Thus the forest supervisor and forest planner, who often have to meet with the public to discuss FORPLAN results, may have no clear idea about the forest planning model that is producing the results they are trying to defend.

Fifth, FORPLAN remains a mystery because it represents forest planning problems in ways that run counter to how people think about these problems. Timber management scheduling, with its emphasis on assessing biological sustainability over long periods using homogeneous response units may be second nature to a forester but foreign to other resource specialists. Beyond that, many people find it difficult to plan the forest as a whole, compared with planning for each acre or stand individually. The notion that a forest-wide constraint requires that an acre be managed for some use or at some intensity for the greater good of the entire forest remains unsettling to people.

Sixth, FORPLAN remains a mystery to most people because the model itself remains physically inaccessible to outsiders. Interest groups and academics have provided technical oversight of Forest Service planning in the past; but FORPLAN has not proven very transportable to sites and machines beyond the USDA Fort Collins Computer Center. Thus, the model itself is still not readily available for outside testing and analysis.

Increasing Our Knowledge About FORPLAN

Some steps can still be taken to make FORPLAN less mysterious:

1. Reports on the model structures and use of FORPLAN in national forest planning should be published in the (peer reviewed) scientific literature. Because the National Forest System generally will not do this, work by academics or Forest Service Research personnel will be needed. The recent FORPLAN documentation (Johnson 1986, Johnson et al. 1986), and sessions such as this help somewhat; but they do not substitute for peer-reviewed publication.
2. The latest releases of the FORPLAN model should be made transportable to other sites and types of computers. Toward this end, we at Oregon State are developing an IBM PC-AT[2] form of the latest release of FORPLAN Version 2. Although the PC version will not be able to solve the bigger forest planning models, it could be an extremely valuable teaching and research tool.
3. The national forests need to provide a mechanism for their own people to improve their understanding of how to identify the key factors controlling the FORPLAN analysis, as the objectives and constraints are varied.

Is the FORPLAN Game Over?--The Oregon Experience

For the past 5 years in Oregon, the national forests have been trying to put forest planning and FORPLAN analysis behind them. From repeated announcements of overly optimistic release dates of forest plans, to making completion of the forest plans a critical element in the evaluation of forest supervisors' performance, the Forest Service has been trying to finish the forest plans. However, forest planning is still with us, and probably will be for at least 2 or 3 more years in Oregon.

Forest plans for 3 of Oregon's 13 national forests have been released, and the remaining plans are scheduled for release within the next 6 months. Over 8 years and tens of millions of dollars in the making, these plans hold the key to Oregon's timber-based economy to the year 2000. First indications are that the plans will propose a 20% decline from current timber sales and harvest.

After release of the draft plans, the public has 3 months to comment on the most sophisticated planning effort in natural resources ever attempted in the history of the world. I believe that Oregonians and their governmental officials will need more time to understand these plans.

We in Oregon need more understanding of what the national forests are proposing and why. We need outside review of the technical merit of the underlying assumptions in the plans. And we need to understand the likely timber harvest from other owners. Especially projecting the likely harvest from private industry lands is important in western Oregon. Yet, the inventory information needed for these projections will not be available until early 1987.

The FORPLAN analysis is crucial to increasing the understanding of Oregonians as to what the national forests are proposing and whether it has merit. We need a full airing of the data, assumptions, and philosophy behind the FORPLAN models used in the proposed forest plans. Also, additional FORPLAN analyses undoubtedly will be required to test ideas on the key factors controlling the harvest, and to test proposals for new alternatives that emerge from involvement of the citizens of Oregon and other people from around the country.

At a recent meeting of the American Bar Association, James Torrance, Regional Forester in Region 6, pointed out two general sources of potential public dissatisfaction with the proposed forest plans: (1) lack of understanding of what is being proposed, and (2) different beliefs (values) as to how the forest should be used. He did not point out one other potential source of public dissatisfaction: incomplete, uncreative, and perhaps even shoddy analysis by the national forests in development of the forest plans. Yet many of the current complaints about the forest plans fall into this third area.

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[2] The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

Understanding the quality and completeness of the forest planning analysis will take time, as will the development of information about likely harvests from private landowners in Oregon.

Forest Planning Methodology--Where Is It Headed?

I finish my talk by making some observations and predictions about the future of forest planning methodology:

1. The uncertain future of integrated planning,
2. Difficulties and potential developments in FORPLAN-like models pertaining to considering budget restrictions, ensuring representation of effective prescriptions, and recognizing the multiple outcome nature of actions,
3. The shift from strategic to tactical planning,
4. The virtue of building future forest plans from the ground up, and
5. The role of FORPLAN in finishing the forest plans under construction.

Does Integrated Planning Have a Future?

In 1981, I predicted that a "revolution" would occur in forest planning models as they changed from traditional timber harvest scheduling models reflecting the perspective of timber management to integrated resource planning models reflecting the perspectives of a multitude of resource specialties simultaneously (Johnson 1981). achieving such a multiple resource perspective was difficult. A major impetus behind Version 2 of FORPLAN was the attempt to provide that multiple perspective, or at least to allow the user to choose the particular resource perspective to emphasize.

Maintaining an integrated planning approach requires constant effort. Centrifugal forces in the Forest Service continually threaten to pull apart the cooperation between the resource specialties that form the basis of such integration. Tradition, the budgeting process, training in the resource schools, and the professional subcultures that cut across natural resource organizations all work to divide planning along functional lines.

Land Management Planning has had the responsibility to ensure that no one broke ranks during forest planning; but it remains to be seen whether forest planning has brought a permanent change in the philosophy of planning in the Forest Service. It is still an open question whether the spirit and letter of integrated planning will be transferred down to the District level during plan implementation and up to the Washington office during output target and budget selection.

Considering Budget Realities in FORPLAN

The role of budget constraints in shaping forest plans has never been clear to me. Budgets have traditionally been ignored in long-run forest planning. Rather, the national forests have concentrated on selecting politically acceptable output levels with the belief that the budgets to support that those levels would be forthcoming. Many of the preferred alternatives require a higher budget than currently available, and few of the forest plans present alternatives under somewhat reduced budgets.

Many FORPLAN models probably reflect this lack of concern for budgets, in that they do not have management choices under each emphasis that reflect the possible range of investment and operating cost. Applying a budget constraint in such a case will result in the model finding an inefficient solution in the sense of reducing output or changing the land allocation more than needed. Faced with such difficulties, I worry that budget reductions will cause the national forests to abandon their forest planning models, and the tremendous amount of work they represent, and return to the old rules-of-thumb in deciding what to do.

Finding Efficient Solutions

The problem is one of ensuring that efficient prescriptions for the management of an area are included in the FORPLAN model. This problem is especially difficult, because the most "efficient" prescriptions depend on the objectives and constraints of the particular alternative.

Most of the focus on constraints has dealt with the explicit right-hand sides that appear in the linear programs created by FORPLAN. Much less effort has been spent on the constraints implicit in the prescriptions recognized in the linear program for management of an area. Yet, these latter constraints can have as large an effect on the solution as the explicit right-hand sides. And they do not produce a trail of shadow prices that can help highlight their importance.

Some of the outside review of forest plans in Oregon and elsewhere will concentrate on whether the national forests have introduced arbitrary constraints into their models through the choices that are represented. Future advances in forest planning also are likely to include breakthroughs in this area.

Recognizing the Multiple Outcome Nature of Forest Actions

Despite the great uncertainty surrounding forest management, foresters have traditionally assumed that they had a perfect vision of the effect of their actions and of the future value of their outputs. FORPLAN represents this perspective through the allowance of only one outcome associated with each action or event.

In FORPLAN, investing in a timber stand or a recreation area does not produce a multitude of outcomes with different probabilities, but rather a single outcome with a probability of 1.0. The natural growth of some timber stands does not show a portion of the acres dying each decade, but rather steady aging through the planning periods. Over the next 10 years, I expect to see the recognition of multiple outcomes in forest planning. That work has begun with the recent efforts by Tom Stuart and me (1984), and Reed and Enrico (1985).

From Strategic to Tactical Planning

As forest planning moves from setting land allocations and output targets to implementing these results for the first decade, strategic planning models will gradually fade out of the picture. Linear programming-based models, such as FORPLAN, are useful for setting broad guidelines for management of the forest through time, but are much less useful for the project planning across space that accompanies plan implementation.

A new class of models is arising for short-term spatial analysis based on network optimization instead of mathematical programming. Emphasizing road management scheduling and project selection, these models will focus on finding efficient strategies for plan implementation, given output targets and detailed spatial constraints for particular areas on the forest.

These models will be the focus of attention within 5 years as the controversy over the use of public land switches from what should be the land allocation and output targets for each forest to what actions should occur on each drainage and plot of ground. By explicitly representing spatial considerations, such as clearcut size restrictions (adjacency constraints), these models can more accurately reflect the realities of project selection.

Building Forest Plans from the Ground Up: Salvation or Folly?

The results from this analysis could, in turn, become the basic building blocks for the next set of forest plans just as the forest plans are, in theory, the building blocks for the Resources Planning Act assessment and program. Building the forest planning choices from the ground up would allow for more accurate representation of the spatial considerations, such as the stand-adjacency constraints, than possible in current forest planning efforts.

Such a suggestion has been made during this planning effort and is discussed in the FORPLAN Version 2 Overview (Johnson et al. 1986). However, except for some forests that are creating packaged choices for critical areas on the forest for the few planning periods, little use has been made of the approach.

Dividing the forest into watersheds for forest planning and representing the alternatives for each watershed through spatially feasible package choices describing a set of actions over time for these areas is a fine objective. No one should suppose, though, that it will simplify forest planning.

Developing choices for watersheds while recognizing the actual distribution of stands in each area, ensuring that the necessary range of choice exists to enable efficient forest-wide solutions, and reflecting all the environmental constraints on potential actions is a formidable task.

Forest planning has always been hamstrung by its attempts to make programmatic statements about effects that are aggregations of individual actions on the forest over time, without actually representing the actions in the planning models measuring the effects. Doing in-depth analyses of the feasible actions on individual areas and then representing packages of these actions through time as choices in a forest-wide planning model would bring together the measurement of environmental effects and the actions underlying them.

But there is a drawback to this approach. Barber (1986) rails against the continual introduction of complexity and detail into forest planning. Yet, the proposal I have outlined here, and have often made in other contexts, does just that.

If forest planning has taken more than a temporary aberration in the direction of quantitative planning, then the agency must face the widening gulf between the people doing this analysis and the people whose problems the analysis is set up to solve.

We are close to that situation now on some national forests. Models that cannot be explained are not progress. Models so complicated and costly to check that they are beyond inside and outside review have no place in public land management.

The time is long overdue for the Forest Service and its outside critics to begin to suggest the sideboards over complexity and sophistication that will be allowed on models that deal with the important issues in management of the national forests.

FORPLAN's Role in Finishing the Forest Plans

Turning the problems that now exist with forest planning models over to operations research technicians and systems analysts for repair will probably result in more complex and sophisticated models. That approach may help future planning efforts, but will not help finish the forest plans.

Rather, we need to learn how to use the analysis that has been created so far to define the choices available for management of the national forests and to use models such as FORPLAN creatively to search for new alternatives that better integrate the interests of the competing factions in national forest planning.

The national forests may have worn themselves out in preparation of the draft plans, and outside groups and institutions may need to take a stronger role in helping to complete the forest plans. I believe outside oversight will be needed to ensure that a fair and high quality cumulative economic effects analysis is done.

Involvement of these traditional constituencies, however, is not enough to complete the forest plans in a state such as Oregon. We also will need the formation of broadly-based citizen groups working with the Forest Service, perhaps through professional mediators, to find areas of common agreement and to suggest alternatives to the Forest Service proposals, where needed, that more satisfactorily mesh their interests.

Especially in Oregon, where almost all issues revolve around the allowable sale quality, the FORPLAN analysis has a potentially significant role to play. Both in terms of the need for people to know what key factors control the harvest, and in providing an assessment of what any proposal means in terms of ASQ, FORPLAN has a continuing function.

Until now, FORPLAN's major function has been to help forest planning teams evaluate the implications of each forest planning alternative. The real challenge of the FORPLAN work in the near future is to make it useful in the next phase of forest planning when outside groups and individuals have a larger role. The FORPLAN analysis is not over--it has just gained a new set of clients.

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Session II:

Experience in the Implementation of FORPLAN by Industry and State and Provincial Governments.

FORPLAN in the University: Berkeley's Experience

Lawrence S. Davis[1]

Abstract.--Six requirements are identified to successfully install and sustain the use of FORPLAN in a university environment. The most critical is the need for faculty expertise to efficiently teach the use of FORPLAN. Forest management research is classified by three attributes: (1) aggregation level of analysis, (2) source of data, and (3) kind of research. FORPLAN is ideally suited to empirical analysis at the ownership level of aggregation.

It's worth saying again for the record that the national forest planning problem has to be the most complex we've ever attempted to model and analyze using linear programming. In its purely analytical dimensions the problem's multiple goals, multiple outputs, multiple decision makers and multiple planning periods for heterogeneous land tracts of 1 million acres lets us easily conceive of linear program matrices with more than 1 million columns and 20,000 rows. Reality forces us to compromise on less, at least for now, and there is real concern that present models already may be too large.

All this multiplicity doesn't even consider the political and legal dimensions of public lands that regularly alter both the rules of planning and the objectives and constraints of the planning problem. Al Dyer once gave me the rules for the TINKERTOY[2] game where small groups of people are given a standard box of tinkertoys and told in statements written on the blackboard to "build the highest free-standing structure possible under three rules: (1) there are 20 minutes to plan, (2) 40 seconds to build, and (3) no pre-fitting of parts while planning." I've used the game 15 or so times and its now abundantly clear that many people have a hard time understanding these simple planning instructions. They often build feasible, well engineered, sturdy structures no higher than 6 inches that a truck could drive over. The rules, alas, did not ask that the structure support a truck, but only that it stand long enough to be measured. I occasionally illustrate national forest planning in this game context by waiting until there are about 2 minutes left to plan and then loudly scream that" you can no longer use the blue sticks, no more than four of the orange connectors, and only three people in the group can physically participate in the building." The result of this last minute change is usually anger, dissension in the groups, and some quitting the game.

Fortunately in class we have an option not available in the real world -- to relent and proceed with the original game. After terrorizing the student planners it prompts good discussion about how the planning problem can change faster than we can model it. Land owners and decision makers always will have ever-changing goals, constraints, and problem solving procedures and rules do get politicized in the real world.

Dealing with such complex and dynamically changing problems requires powerful, flexible, and easily revised analytical aids and problem data. I think the FORPLAN matrix generator and report writer was forged in such an environment and has developed to be such an aid. It's now time for it to spin off from its USFS home to let the academic, private and other public agency communities concerned with long-term land resource planning problems use and expand its power. There are many challenging and exciting FORPLAN applications beyond national forest planning: macro level problems of state resource planning, integrating federal and state planning, national level resource planning in developing countries, industrial application, and micro planning at the small private forest owner or village agroforestry systems level.

As a fellow traveler on the fringes of FORPLAN development, I watched its development from MUSYC through release 10 of FORPLAN 2. Most of this was at Utah State University working with Norm Johnson, Kim Marshall and the dozen or so students caught up in the heady excitement of forest planning. I finally escaped my department head chores and moved to Berkeley in 1982 where I'm now trying to recapture normal life as a forest management professor. I always had thought FORPLAN had great potential as a forest management research tool; and finally I have my chance.

This paper reports a case study of one academic's initial successes and failures in transplanting FORPLAN to a university and building a research program around it. I report from the viewpoint of one who uses FORPLAN but has to rely on others for technical support. I have few numbers to report, because none of the studies are finished. However, I'll (1) describe what seem to be the minimum resource requirements needed to successfully support and use FORPLAN at a university, (2) discuss the kinds of research for which FORPLAN is particularly well suited, and (3) briefly describe the research problems and applications we have underway at Berkeley.

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[2] The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

INSTALLATION AND SUPPORT REQUIREMENTS

If you are anything like me, when you open the shipping box and look at the 9-track tape labeled FORPLAN, an overwhelming reality hits that you have no Fort Collins Computer Center (FCCC), no handy Norm Johnsons, Tom Stuarts, Kim Marshalls, or Jim Kellys, you are not a programmer, and you have limited skills with the campus mainframe operating system. In short, you are truly on your own. If you can get past the urge to mail the tape back, then you have to make the commitment to build your own support system and stand independent of the Forest Service. A local support system has the following important elements.

1. A mainframe computer with adequate disk, tape, and cpu capacity, a large and well-supported linear programming package, and, it is hoped, a bargain rate schedule.

At Berkeley we're blessed with a trouble-free, souped up IBM[2] 3081 that has a good rate schedule. The only potential issue is the computer center's rising reluctance to pay the support cost of MPSX as campus overhead. Surprisingly, only a few people on campus are working with large scale linear programs, and the computer center may try to charge the $15,000 annual support cost against us few users. If MUSYC and FORPLAN move to the PC-AT[2] as rumored, then this requirement may be more easily satisfied, particularly for matrix generation and running small test, teaching, and research problems.

2. Operating system support staff who understand the operating characteristics of FORPLAN and can write a menu-type executable or job control language which assigns, opens, and closes files, lets you easily implement one of a dozen or so packages of execution runs, provides comprehensible error messages, and keeps track of costs.

After several false starts I discovered Al Stangenberger who has developed as a master of the mainframe CMS operating system. We obtained the IBM[2] converted version of FORPLAN II, release 4 from FCCC and struggled to get it compiled. A new FORTRAN compiler helped and by the time we received a copy of FORPLAN II release 10 it went up quickly and is fully converted to FORTRAN 77.

At the critical installation point, we hired Kim Marshall from Logan to consult for two days and he and Al roughed out the operating system control package. Al has subsequently refined it and prepared help menus to the point where I can understand and comfortably execute runs. Release 10 with the source and object codes, the CMS executable, OS job control language, and the Tom Stuart problem sets is what we have been sending people who want to try FORPLAN themselves on the IBM.[2]

3. Teaching program in modeling forest management planning problems, including instructors and courses to teach students, research technicians, and interested faculty the many conceptual and mathematical structure options for building linear models of forest planning decision problems. Supporting courses in mathematical programming, operations research, economics, business, and policy also are needed.

At Berkeley I do this teaching. My senior and graduate forest management courses appear adequate to get the students started and we have excellent support in the disciplinary departments. I've been doing most of my research work with graduate students and, to state the obvious, a university has to offer graduate programs in forest management and economics if good students are to be attracted and the research program is to be sustainable.

4. Continuing capability to teach FORPLAN including the many option for preparation of problem data and files, understanding how these files relate to the many different conceptual and mathematical problem formulations possible, understanding the users manual, interpreting error messages, effectively debugging problem files, and guided practice from simple through complex formulations.

I am finding this to be the most difficult requirement to satisfy. I sat through some of the initial FORPLAN short courses at Logan but my real personal training came when Tom Stuart kindly came to Berkeley and put on a very intensive 3-day training program for about 15 students and faculty. We mainly went through the set of staged problems he built to illustrate FORPLAN's capabilities. The copious notes and scribbles on my computer printout "textbook" is my primary reference to this day.

I have copies of his problems and used them last fall to teach my graduate class how to use the system. The students also modified a simple timber management problem file, executed a few runs and interpreted the results. But, like most of you, I have to do other things. When returning to FORPLAN after a 6-month vacation from its details and then trying to help a student debug a problem, I find it isn't so easy to remember all those symbols and rules or exactly how coordinated scheduling works.

I've about decided that not only must I maintain a research program using FORPLAN, I must regularly build files and use the system to keep up a skill level needed to teach and transfer the technology to a continuously changing group of students and other users. I think it's critical that at least one regular faculty person commit to FORPLAN as a primary skill area and the center of research, outreach, and consulting for a long time. Otherwise you or the university could be in the embarrassing fix of having put up FORPLAN but nobody remembers how to use it.

5. Access to high-level consultation to resolve difficult problems and errors and to determine if the cause is your file preparation or the code itself.

The few times I needed such service I leaned on old friends. However, I can envision more frequent needs as we start new and different problem formulations that break little known or untested rule combinations. One way or another, such high level consulting is needed by new and occasional users. If the Forest Service cannot regularly provide this service for free, maybe they could charge for the consultation? Perhaps we non-USFS users could help ourselves by establishing a users group and identifying the people to network with.

6. Money to implement items 1-5. This takes an institution or grantors willing and able to invest in people

Table 1.--A multi-attribute classification of management and planning research

Attribute I: AGGREGATION LEVEL OF ANALYSIS

- A. Stand and stand type questions and problems
- B. Forest or ownership level policy, decision and implementation problems
- C. Multiple ownership regional, state, and national level resource allocation, supply and policy problems

Attribute II: SOURCE OF DATA

- A. You borrow data sets developed by others
- B. You create original data sets

Attribute III: KINDS OF RESEARCH

- A. Conceptual and developmental studies
  1. Pure theory and model derivation
  2. Tricks and techniques to formulate new or difficult problems for solution by existing models and algorithms
  3. Demonstration of theories and techniques on simplified or hypothetical data bases
  4. Creating new analytical tools and software.
- B. Empirical Analysis and Hypothesis Testing
  1. Sensitivity analysis and hypothesis testing to understand the effect of input data, problem formulation strategies, or stochastic properties of model coefficients.
  2. Policy, planning, and decision analysis. Manipulating problem variables under control of decision makers to quantitatively estimate benefits, costs, and implications. Creating alternative problem formulations to reflect different decision-maker viewpoints.
  3. Validated experiments comparing model results with the measured reality of historical records or forward looking longitudinal studies and monitoring data.

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and pay the computer charges while a program is developing, the users are learning their trade, and data bases are being established. After you get started and pay some dues, grandiose plans for many new data bases and extensive analysis roll forth. Then, more money is needed.

FORPLAN'S ROLE IN THE GROVES OF ACADEME

To justify the considerable investment required to establish a FORPLAN based research program, program benefits need to be identifiable and substantial. For private companies or consultants, the benefits are increased profits from selling better company services, reducing costs, or improved resource allocation efficiency. Seth Peters of Boise will give us glimpse of the private company application and perhaps some of the consulting companies putting the system up may want to comment from that perspective.

At the university benefits are measured by teaching, research, and extension results and for the individual professor, the primary benefits are necessarily publications that lead to fame, fortune, and tenure. This paper takes the university research perspective and dwells primarily on how FORPLAN could fit into a forest management, economics, and policy research program. First I'll present a classification of management and planning research and then relate it to FORPLAN to discuss possibilities and limitations. The classification shown in table 1 organizes research questions and projects by three attributes affecting the problem size, data needs, tools and cost of such research. I'll avoid the temptation to classify our management economics literature in this framework and look at it as a new researcher implementing FORPLAN as a research tool.

Management and Planning Research: Classification and Development

Research costs and computational complexity increase with shifts from stand to forest to multi-forest aggregation levels and with shifts from conceptual to empirical studies. Costs can markedly increase when original data sets are constructed by the researcher. Its not surprising therefore that much of the early literature of forest economics and management focused on theoretical and empirical study of stand level questions such as "what is the optimal rotation and cultural schedule." Such work was directly based on economic theory, computationally satisfying, and the empirical data was not prohibitively expensive. The early financial maturity analyses of Duerr and the many current papers using dynamic programming are good examples of this research.

When computers and linear programming became available, we finally could deal effectively with forest or ownership level questions and quantitatively evaluate harvest schedules, questions of harvest flow policy, and investment in intensive management. When timber RAM and some of the binary search simulators developed to handle large problems and several western national forests created reasonably accurate data bases, then we could finally estimate the empirical import of the allowable cut effect (ACE) and related harvest policy questions. Several studies used many different forest data bases for policy analysis of old growth disposition and to refine the operational definition and meaning of sustained yield.

Research Opportunities for FORPLAN

An era of serious empirical multiple use tradeoff research has just now arrived stimulated largely by the current round of national forest planning that mandated consideration of empirical and value tradeoffs between all forest outputs. Our traditional preoccupation with timber production and timber policy research concurrently is giving way to examination of these much more complicated spatially, temporally, vertically and horizontally linked multiple output production problems. These are the problems FORPLAN is designed for: multiple-use empirical research at the firm or enterprise level in terms of the classification, research fitting attributes **I-B, II-A,-B,** and **III-B-1,-2,-3** are the central domain of direct FORPLAN research applications (the creation of FORPLAN itself would be a **III-A-4** study).

A classic study of the **III-B-3** type applied to multiple forest data sets was the roadless area tradeoff study by Randall et. al. (1979). Many administrative studies conducted by the NFS are of this type such as the commercial thinning study headed by Sarah Crim (1983) in Region 6 and the statewide cumulative effect study underway in Idaho and those starting in Oregon and California.

For the university the most expensive aspect FORPLAN research can be obtaining full scale data sets. Borrowing data sets is an obvious way to keep costs down; but our current options are limited to borrowing national forest data sets.

These are large data sets developed at a cost far greater than what nearly any university could afford. However, then we must work with national forest lands and accept as given their land stratifications, prescriptions and much of the basic yield and management response data. To seriously rework the files would require that we also have the maps and much of the source data used by the forests. The forests may not want or be able to supply all the data we want, nor be willing to pay for their analysts and managers to spend enough time educating the academic about the problem formulation details and rationale such as, "Why are the constraints were set this way?" or "Who supplied the various subjective coefficients?" There still are many opportunities for sensitivity and aggregate policy analysis research using NFS data sets, and I'd expect to see considerable research of this type. It might be profitable for us to discuss how the USFS, the universities, and affected parties could be more effective partners in this effort.

Creation of new data bases carefully designed to examine specified research questions will surely be the heartfelt desire of any serious forest management researcher. Original mapping and inventory is expensive, especially if you want accuracy sufficient for convincing ground truth validation. Many times you will want to re-stratify the land base, say to look at different allocation zones or different ways to model wildlife habitat, and this requires a reasonably high resolution spatial data base and a geographic information systems to use it. Timber inventory plot records have to be located spatially or be identified by enough strata labels or bio-physical land attributes that they can be sorted and regrouped to match the chosen land strata. Another aspect of data base development is that it's slow business. It could take 3 to 5 years to finish a data base ready for research use--dangerous strategy for the untenured professor.

Some universities have a well-documented management-oriented research forest and most of the needed primary data is already available. This source provides the first independent data base we are building at Berkeley. We have also recently organized the California Forestry Research Cooperators which includes Industrial, State, Federal, and University members. We have a management/economics project and hope to use this as a means to build several data sets.

It would be good, for example, to use several representative private land data bases in FORPLAN as a sample of the state to empirically evaluate the impact on the private landowners of proposed state forestry regulations and other policies. I'm also persuaded that FORPLAN could be a useful and effective tool for planning, managing, and doing management research on small properties of 2,000 to 10,000 acres. The trick here would be to pre-package a large menu of identifiers (particularly timber condition classes), prescriptions, yield files, and economic data sets for the general forest area in question. Then for an individual owner problem all that would be entered is the owner's unique analysis areas, goals, and constraints.

A third kind of data set is the fake and half-fake forest. Fake or artificially generated inventory and growth data for many different stand and land types can be used to create artificial forests by attaching different acreage to these stand types. For spatial assessment these types also could be assigned to the mapped cover type polygons of a real but uninteresting or uninventoried forest. The half-fake forest would use real inventory data to define stand types but the acres assigned to each stand or stand type is chosen for research purposes. While fake forests are not samples of reality, they are inexpensive and effective data bases for some sensitivity analysis and some kinds of policy analysis studies. What they cannot do is support aggregate quantitative estimates of policy implications.

CURRENT FORPLAN APPLICATIONS AT BERKELEY

We now use FORPLAN for two well-defined research applications, and two more are in the works. Also, it has been used in teaching and may possibly be used for consulting. These projects and activities are as follows:

Forest Management at Blodgett Forest Research Station.

Our main studies started with creating a high-resolution data base for our 3,000-acre research forest located at 4,000 feet in the mixed conifer type of the Sierra west slope. The data base consists of detailed maps and more than 1,000 permanent inventory plots. The maps are of timber cover type detailed by height in meters, percent crown cover at three heights, and total percent crown cover, slope, elevation, aspect, soil type, roads and stream (by types), plus the contiguous units of watersheds and management compartments. An understory cover map detailed by species, height and density is being prepared. This spatial data base has been digitized and exists as 1/4 hectare grid cell data base in our SPANMAP geographic information system.

A special data layer in the grid data base contains the identification number of 1,000 permanent inventory plots by the grid cell in which they occur. This allows us to intersect and stratify the land in many ways and produce a list of plots that fall in each strata. This plot list is then used to organized the plot records in a R5000 data base, push them through the CACTOS growth and yield simulator, average all plots in a strata, and produce yield files directly in FORPLAN format. A couple of clever students, Peter Daugherty and Mark Jamnick, developed the software and procedures to do this labor saving file manipulation work on the PC.

We plan to make the data base dynamic by updating the vegetation cover type map every year and saving each year as a data layer. This will allow detailed longitudinal tracking of cutting patterns and the associated wildlife and range habitats, edges, clumps, corridors, visual character, and other issues related to spatial dynamics. This should enable us to do some work on the vexing problem of linking planning to implementation on the ground and to help refine the meaning of "spatial feasibility."

This data base has taken 3 years to put together, and we think it will allow us to efficiently develop FORPLAN data bases for many different problems and research questions. The biggest limitation of Blodgett as an empirical data base is that it is all excellent site and grows trees like mad. To model a more typical forest with site II and III land, we will have to obtain the yield data elsewhere and artificially lower the site of some compartments in the models. Much of the Blodgett data already existed and some of the hardware and software was free or being built for other projects. However, it still cost us about $15,000 in direct costs plus my time and some time by the permanent staff at the forest. If you had to create a comparable data base from scratch and pay all the costs, it probably would be between $50,000 and $100,000 for a 3,000-acre tract. Three studies are now using this data base.

Effect of Alternative Land Classification on Calculated Forest Outputs

The first is looking at the effect on even-aged harvest schedules of strata based vs. area based land classification at several different levels of classification resolution each. This sensitivity study will be run on several different starting forest inventory structures. This project is Mark Jamnick's dissertation work and should be completed within a year.

One of the more difficult issues is how to make meaningful comparisons between harvest schedules, because almost every different formulation implies a different goal or constraint set. For example, if area based models are used then this generally implies that there are some spatial constraints in the problem modeled--else why use compartments? It would seem that to fairly compare yields and outputs from a contiguous but heterogeneous area-defined problem to a homogeneous strata-defined problem requires that the spatial constraints implicit in the area formulation are comparably imposed on the strata model.

Conditions Favoring Even- vs. Uneven-aged Management Systems

The second study is using the basic data developed by Jamnick and adding a large number of single tree selection uneven-aged prescriptions plus some small group selection uneven-aged prescriptions. The small (1- to 3-acre) harvest areas of small group selection are themselves even-aged but may have different yield properties because of competition with adjacent older adjacent stands. Collectively a well designed dynamic mosaic of small cuts may be able to emulate visual and other qualities of single tree selection. We want to explore the differences between even-aged, uneven-aged, and small-group selection management at the forest or ownership level and to identify the range of goal, constraint, species, initial forest structure, yields, price and cost conditions that cause movement of prescription choices between these management systems.

Management of Small Forests: Blodgett as a Case Study

The third study is management of Blodgett itself. We need to set up a long-term operational plan for the forest to guide our actual harvesting and cultural program. Blodgett makes most of its operating income from timber sales. The current cut is about two million board feet and this is about our estimated LTSY. Our objective is to maximize the first period net income subject to non-declining undiscounted net income and subject to a myriad of spatial constraints related to research programs and also integer controls to require cutting an entire even-aged compartment whenever it is entered. The applied research question here is "how well can FORPLAN handle this sort of a problem and can gains in efficiency be found for properties as small as 3,000 acres that more than cover all costs of using FORPLAN?"

The California Forest and Rangeland Assessment Program

A second major application of FORPLAN is to integrate data and organize the reports for the simulation model used to estimate alternative future trends in ownership, use, activities, and outputs from California's public and private forests and rangelands. In concept and substance this state-level assessment is much like the RPA assessment required of the Forest Service.

We have built a simulator called CALPLAN (Davis et. al. 1986) that models the non-Forest Service lands of the state by stratifying the land by county, cover type, owner, and owner objective (which we call "owner behavior class"). Alternative futures are modeled as changes in the distribution of area by cover type, owner, and owner behavior. Who owns the land and what they are likely to use it for drives this simulation. These changes are subjectively projected by expert opinion based on interpretation of past trends, county planning, possible state policy and various assumptions about demographics and the state's economy. The simulator has many elements (fig. 1). We also have taken the final step, and view the program purely as a simulator, prompted mainly by the lack of a meaningful aggregate objective function for private lands in the State. We skip the idea of optimization entirely and directly simulate a linear programming solution file as the output of the model. The solution consists of an allocation of current land types, ownership and behavior (analysis areas) to future owner/behavior classes (prescriptions). The FORPLAN report writer picks up the hardwired solution plus all the activities, outputs, costs, and yields associated with these strata and prescriptions in the yield and problem files, and writes out a report. We have tested this procedure with small- to medium-scale problems, and it works. I expect that computer will be relatively low, because we have skipped the matrix generator and the LP solution costs.

The solution for the state's private lands will contain about 150,000 non-zero variables and the report writer will summarize on more than 100 activities and outputs at various levels of aggregation. Robin Marose has put together all the software to run CALPLAN and stripped and changed a copy of the FORPLAN code to efficiently serve purely as a report writer on this simplified but large scale problem.

The Forest Service lands are modeled by including the preferred plan of each national forest and its associated outputs as a column in our solution file. As best we can (the documentation and facts are scarce) we're including the current plan and level of output from all other public ownerships as additional columns.

As a post-CALPLAN/FORPLAN extension, we are simultaneously considering all Forest Service plan alternatives along with multiple options for private lands. The private land options are modeled by different CALPLAN scenarios driven by different state policy assumptions about investments, regulations, etc. This menu of all public and private choices will allow some regionalized sub-state and state-wide analysis of cumulative effects and can help define the range of collective choices for integrated federal state resource planning. Some preliminary runs suggest that the current national forest planning alternatives are not well designed to illuminate possible between-forest or forest-to-private tradeoffs, that many alternatives are infeasible at current budget levels, and that the independent forest-at-a-time schedule for review and comment precludes substantive state level input.

Other Applications of FORPLAN

Two additional projects that make use of FORPLAN are in the formation stage. The first is an outgrowth of the Blodgett application and will more extensively test the applicability and efficiency gains from sophisticated analysis of small private forest properties. The forest management cooperative program with forest products companies in California has three sequential projects. The first is to build an economic stand evaluator to couple with growth and yield models.

The second project is to semi-automate a linear programming analysis of the short-term (5- to 10-year) scheduling of sales or purchases of stumpage with financial objectives and under constraints over time on cash flow, species mixes, etc. This model will use the stand evaluator model to prepare the column data for each stumpage sale option.

The final project will go to long-term planning, where it may be possible to effectively use FORPLAN. We are making the yield and economic data for the stand evaluator and sale scheduler compatible with the input formats of this data in FORPLAN.

For a different application altogether, I have students in the undergraduate class make LP models of a village agroforestry system. Sometimes these hand-entered problems run to 3,000 columns and 500 row matrices which we solve with a combination of LINDO and MPSX. One graduate student took this another step and managed to replicate such a problem in FORPLAN. Because the agroforestry problem simultaneously considers a combination of a land allocation and crop production problem, a nutrition problem, a population growth problem, a crop and labor import-export problem, and a competitive market problem, the students typically make a hundred or so runs to test and do sensitivity analysis on many possible variables. The question to explore is can we speed this up with FORPLAN and make use of the report writer to eliminate much of the tedious hand processing of results.

SUMMARY

FORPLAN unquestionably has great potential as an analytical research aid to investigate important and interesting management and policy questions at the forest or enterprise level. This will not be easy or cheap research, because high resolution, large scale data bases must be built or borrowed to characterize realistic forest ownerships. For the larger state and national level policy questions, each ownership is but one observation -a sample of the land base- and several such forest data sets are needed to give a

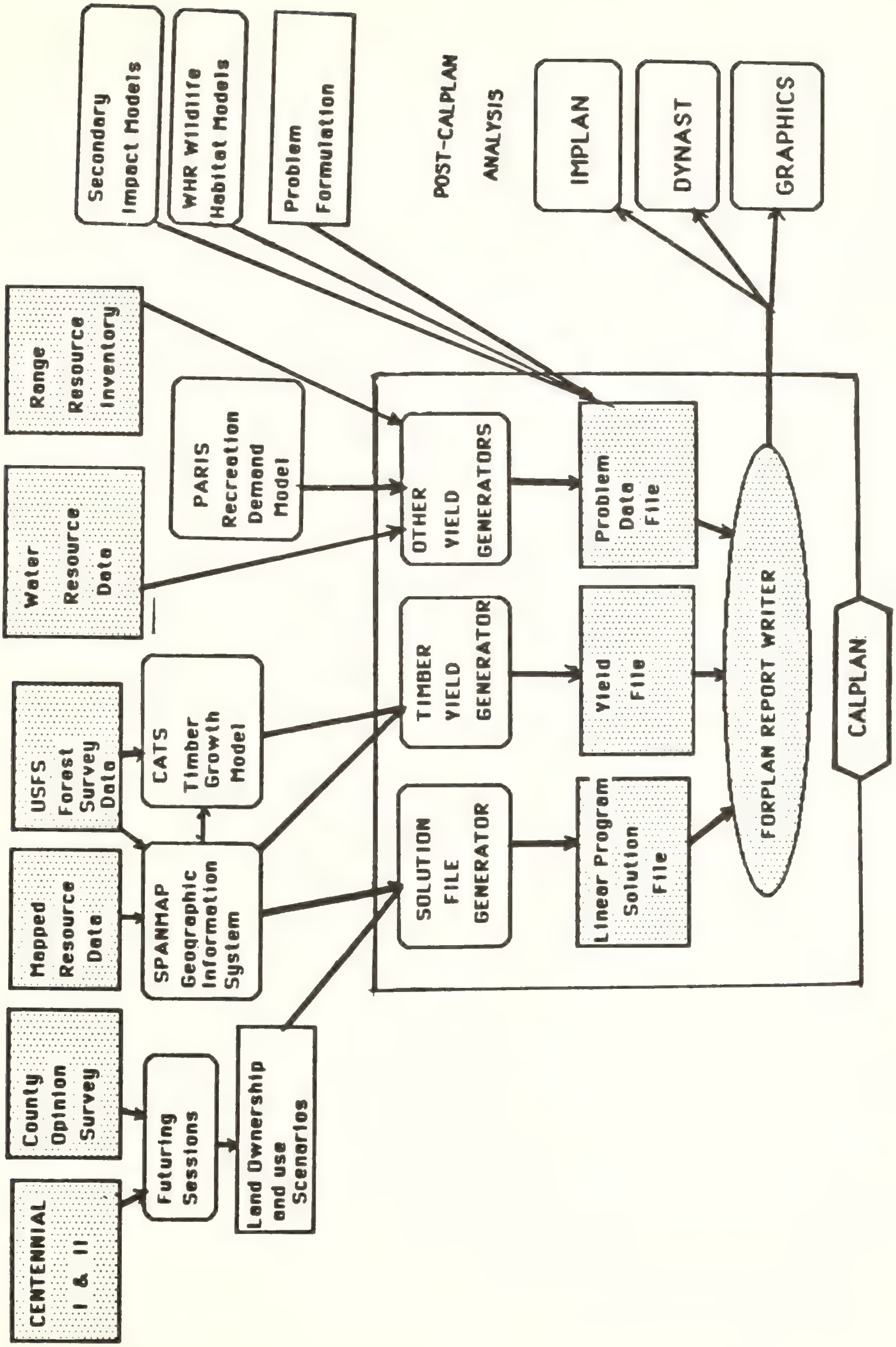

Figure 1.--CALPLAN: The California Forest and Rangeland Assessment Model; principal data and computational elements.

big enough sample to reliably estimate regional, state or national implications.

Besides the data cost, the parent institution and one or more faculty (or other long-term personnel) must invest in setting up the training, student, consulting, and computer system infrastructure needed to effectively run a FORPLAN based research program. I think we could fruitfully explore some sort of a consortium or multi-university network in some sort of a partnership with the Forest Service to share knowledge, data sets, and training to make better use of our limited resources.

Regardless of cost or difficulty - it's exciting that FORPLAN finally gives us a tool to do empirical research on complex forest level management problems.

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Boise Cascade Corporation: The FORPLAN Experience

Walt Mott and Seth Peters[1]

Abstract.--This paper discusses the linear programming capabilities, validity, and history of FORPLAN at Boise Cascade, along with the philosophy, modeling importance and source code modifications necessary for the successful implementation and use of FORPLAN in managing the Company's timberland asset.

Boise Cascade Corporation is an integrated forest products company engaged in the manufacture, sale and distribution of paper, office products, packaging and building products, both domestically and abroad. To support these operations in the U.S. and Canada, Boise Cascade manages over 6,000,000 acres of timberlands. These timberlands are managed by 13 operating regions spread across the continental United States and the Province of Ontario Canada. Recognizing that these timberlands represent a tremendous investment -- millions of dollars for the company -- it is not surprising that the company will continue to search for the best methods to manage these lands. Whether these methods result from new technologies, new or revised silvicultural practices or the use of quantitative models for better understanding our regional forests, we are dedicated to bringing our timberlands up to their full biological and economic potential. The objectives for our forest management program reflect this viewpoint. These objectives are:

1. Maintain a continuous and dependable supply of raw material for sale, trade or conversion.
2. Maximize the pretax return on total capital (PROTC) over the long term from our owned and controlled timberlands.

Both objectives emphasize that timberlands are not to be managed for only short-term gain. We believe the "long-term going concern" philosophy is the most efficient managerial approach to provide society with the quality products that it demands at the lowest possible cost. Trees take time to mature into resources that can be used to make paper and solid wood products, requiring long-term investment, managerial outlooks, budgets and plans. With such long-term biological outlooks and financial return periods and with timber availability and prices facing an unknown future, it is crucial that we improve our ability to effectively manage our forests to remain competitive in a very tough operating and investment environment.

The second objective recognizes and emphasizes that timberlands are an asset and, as such, must provide an adequate return to the corporation. The use of monetary measures for evaluating our timberlands is essential. Our performance is based on how well we operate and the return provided to shareholders and society, within the confines of the environmental, social and political responsibilities of our operations.

To achieve these objectives requires us to find the best set of forest management plans for our operating regions over time. This involves analyzing a variety of silvicultural options and harvest strategies for each timber stand and evaluating how these relate to the productivity of the regional forest. In addition, a variety of future economic and political scenarios are analyzed in order to remain sensitive and flexible to the changing external environment which directly and indirectly affects the way we do business. To help us in these efforts, a continuous forest inventory system and a management and geographical information system is maintained in each of our regions. Also, a variety of quantitative models are used for evaluating forest management planning options and issues.

One type of modeling technique we use extensively is linear programming. In particular, many of the design features available within the FORPLAN modeling regime have greatly enhanced the capabilities and utility of using a linear programming approach for analyzing and evaluating timberland management issues at Boise Cascade.

Advantages of Linear Programming and FORPLAN

For the past 10 years, Boise Cascade has used several linear programming models as an aid in developing forest management plans. Timber-RAM, MUSYC and FORPLAN are examples. We have found that the linear programming approach provides us with some unique advantages, which, in total, are not readily available from other quantitative models. Some of the most important advantages are:

1. The recognition that a tremendous amount of software development and support has centered on the use of linear programming for timber harvest scheduling and forest planning. Linear programming is a well-developed and accepted

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mathematical technique with years of testing and research to backup procedures, algorithmic methods and reporting capabilities for detailing what the solution means. This results in a more production-oriented environment as opposed to a research- or test-oriented environment. It is simpler and more cost effective to modify existing programs to fit specific needs rather than embark on a totally new software development project. This is especially true when one considers the amount of human and physical resources required to design and develop a harvest scheduling program from scratch.

2. Linear programming models provide our regions the basis to quantify the short-term and long-term operating characteristics for the lands they manage and how these characteristics are influenced by the external environment. As such, regional and corporate planners become more sensitive about how changes in the environmental, political and economical arenas affect the operating characteristics over time. Because FORPLAN allows the user to detail important operational parameters, this model has become an important planning tool for several of our operating regions. Previous timber harvest scheduling models are rapidly becoming obsolete as more regions adopt FORPLAN modeling methods.

3. The structure of linear programming models provides the means to evaluate thousands of treatment alternatives for the regional forest. Thus, we are in a much better position for making "sound" forest management planning decisions and to remain flexible for evaluating changes in external forces which impact our business. FORPLAN is especially sensitive in this area. This is one of the major reasons FORPLAN was implemented at Boise Cascade.

4. Another important advantage of linear programs, especially FORPLAN, is the capability to define complex networks. The linear programming approach combined with FORPLAN modeling design provides the means to link discrete parcels of timberlands and associated treatment alternatives to regional forest objectives and operational requirements. Per-acre analysis from growth simulators, such as MFPS or PROGNOSIS, provide for an in-depth evaluation on the best ways to manage individual timber stands. The linear programming model combines all the per-acre analyses into a single composite representation of the regional forest and then subjects the forest to real-world operating constraints to find the best set of treatment alternatives. Given the complexity of determining an allowable cut on large ownerships, this linkage becomes an important requirement to develop a feasible forest management plan.

5. Finally, linear programming and FORPLAN also provide a quick method for evaluating the sensitivity of alternative treatments under a variety of economic, environmental and political scenarios. Previous harvest models had limitations that greatly reduced the sensitivity of alternatives. Though the optimal solution provides excellent direction for formulating a forest management plan, it is not a static finding. The solution is usually only optimal over a narrow range of operating characteristics and assumptions. Sensitivity analysis provides for evaluating what these ranges are, and visualizing what the new optimal solution looks like when the operating characteristics or assumptions are changed. This type of approach is a necessity in the development of a flexible management plan.

Why Use FORPLAN?

The original purpose for linear programs such as Timber-RAM and MUSYC was to determine long-term strategic allowable cut figures, as well as analyzing timberland acquisitions and divestitures. We, at Boise Cascade, wanted something that is sensitive to long-term growth and harvest patterns, and also would allow us to evaluate the resulting impact on the periodic allowable cut. Some of the older allowable cut calculation techniques, such as Von Montel's formula, Handeshagen's formula or harvest figures based on short-term inventory growth data are very insensitive to long-term, changing forest structure characteristics. It is often difficult, at best, for these techniques to take into account the allowable cut effect.

We also desired a technique that could be used to look at various levels of management and hence, carry out sensitivity analysis on a rapid, comprehensive, cost-effective basis. This allows us to have a conceptual understanding of the possible ramifications of a large-scale change in the management of our timberlands resulting from internal or external environmental, political or economic influences and to be better prepared to deal effectively with these changes in a time-efficient manner.

FORPLAN is well suited for addressing these issues. Once the basic model is built, the various components and linkages that comprise the FORPLAN modeling regime provide users the ability to quickly and easily create a variety of scenarios for describing future markets and operating conditions. Thus we can evaluate the trade-offs that occur both biologically and economically that is a result of a change in how we manage our timberlands.

FORPLAN has been modified to include financial information, such as cash flow, depletion, capitalized investment, net income, capital gains tax, ordinary tax, PROTC and the internal rate of return (IRR). These financial variables, along with the biological results of a model run, are often effectively used to evaluate short-term and long-term impacts of a given management approach as acquisition or divestiture opportunity. Crucial variables such as the allowable cut, net income, cash flow and return on investment can be ascertained helping us to make better decisions about the validity of a given strategy or transaction.

Another area where we use FORPLAN effectively is in silviculture sensitivity analysis, both from a biological and a financial viewpoint. Alternative silvicultural scenarios are created for each stand or timber type and FORPLAN model runs are made addressing certain biological and financial goals. As an example, if a given model structure using today's financial assumptions is run addressing two differing goals -- one of maximizing the net present value (NPV) and one maximizing volume -- the harvest levels, NPV and silvicultural investment levels are often dramatically different. The results of these runs tell us which silvicultural options over the long term meet given financial hurdle rates. Those that do not are often deferred or eliminated as a valid management alternative (unless required by federal, state or local legislation). Those that do meet minimum return rates are emphasized in the silvicultural program.

Operating Goals

We have several important operating requirements for all our linear programs, including FORPLAN. They must be cost effective, as user-friendly as possible and must contain financial information. We put forth much programmer effort to make these programs user-friendly by simplifying input requirements, creating easy-to-understand, comprehensive reports and programming the internal code to optimize operating characteristics of the model. With the size and complexity of programs that address large, complex problems such as allowable cut determination, this is often very difficult to achieve.

To improve the effectiveness and increase the utilization of our models, we attempt to assemble a team with solid modeling background and combine it with up-to-date, cost-effective technology which results in more acceptable real-world answers. We have succeeded in pulling together a group of people who have a background in forestry, economics and operations research. These people work together with operational foresters in designing a large-scale analysis. This combination of skills is necessary to successfully design, solve and implement a linear programming model. Regional foresters are experts on the timberlands they manage, but they often do not have the time nor do they have the experience and skills to build a FORPLAN model from scratch and interpret the resulting solution output.

Interpretation of LP output must be done carefully because of the inherent limitations of any model. Confusion often arises about the validity of the answer or even why a certain optimal solution was reached. Generalized assumptions with no understanding of solution findings can lead to erroneous implementation or planning and budgeting. Having a team of experts helps alleviate these problems by working closely with our operating regions throughout all phases of an allowable cut analysis. In actuality, it is the field personnel who design the model; the team of experts help the regions input data into the model, and interpret results. Therefore, it is through a cooperative effort from both analytical and operational experts that a successful modeling application is achieved.

Boise Cascade's Version of FORPLAN

To help achieve these goals, Boise Cascade has spent more than 5 years of labor in understanding, modifying and implementing FORPLAN (Version 2, Release 3). The effort devoted toward adapting FORPLAN to fit our forest management planning needs has been money well spent. We made these changes after reviewing the model's capabilities and realizing that many of the features available within the FORPLAN framework make this modeling approach vastly superior to other timber harvest models previously used. From our viewpoint, FORPLAN provides the following advantages:

1. The multispecies/multiproduct modeling feature provides the means to link the product demand requirements of our manufacturing operations to our forest inventories. Though a single-weighted average measure of timber volume that reflects a given species/product mix, such as that used by the MUSYC model, may suffice for addressing general forest planning issues, it becomes rather burdensome when trying to accurately and realistically match it to the timber resource requirements of our manufacturing facilities. Each mill has a certain range of species, piece-size and timber volume requirements which it must have to stay profitable. The closer these are modeled within a forest planning framework, the better off we are in evaluating potential inventory/product levels and how they impact operational plans and profits.

2. The ability to define unique activities, outputs, aggregates and associated yields, constraints and economics increases the realism of the model and thus, its general acceptance. Typically, a regional FORPLAN model will use, in total, 20 activities and outputs for describing the silvicultural treatments and harvest options under study. Avoiding superfluous minutiae is critical in a model's structure. Important variables which are known to be sensitive to the internal and external operational environment must be defined and emphasized. Using a relatively small set of activities and outputs, we can not only accurately and realistically portray a silvicultural practice, but also define and evaluate its economic implications under the auspices of an investment analysis approach without confounding the analysis or implementation with unnecessary complexity.

3. The ease and flexibility for entering economics into the model is also a very important advantage. Previous timber harvest models e.g.,

MUSYC, required the user to develop a rigid economic look-up file which was used with other model input found in the processing file. For small linear programming models, this file structure was workable; however, in larger models in which a variety of economic scenarios were being explored, the MUSYC file structure was cumbersome. Whenever a revenue or cost was changed, every economic table for which the change applied would require modification. For a small number of changes, the appropriate economic tables are easily modified; however, with substantial changes in economics, the user had to create a new economic file. This resulted in a less cost-effective model that also took a longer time to restructure. Sometimes, where very quick answers were needed, it was impossible to use the model at all. Therefore, the tool became ineffective for decisionmaking.

Within the FORPLAN modeling regime, all economics are entered directly into the processing file based on stand or volume characteristics instead of being directly linked to a given forest entity/age value. This allows economics to be easily modified, and by using a combination of identifiers, qualifiers and treatment types, it is simple to attach a set of economics to the entire forest or to a unique analysis area prescription combination.

4. FORPLAN provides several other economic features which were nonexistent in other timber harvest models. The ability to define a unique species/product set of real appreciation rates for each activity or output lends more realism for modeling "real-world" phenomena. For example, in the southern region of the United States, we know that the value and appreciation rates for pine sawtimber is markedly different from hardwood sawtimber. Using one value or set of appreciation rates may work fine as a general starting point but is in error when applied to evaluating future markets and operational plans. This is especially true when trying to evaluate shifts in the species- product mix and their economic impact on regional timber supplies.

5. The power of qualifiers for defining a set of economics over a range of activity or output yields is also very important. For example, qualifiers are used in developing logging costs to account for the large cost variations that occur because of product piece size or diameter class.

6. The use of identifiers and in particular, the ability to define the identifier-matching strategies (THEMING) for linking various components of a model together is a powerful feature of FORPLAN. Throughout the FORPLAN modeling regime, the efficient ise of identifiers can decrease data input requirements, which, in turn, help to minimize the size of the processing file and yield file, and related disk storage and processing costs. We have found that the proper use of identifiers can save us hundreds of dollars within a model application. Based on this finding, a set of worksheets and procedures were developed for use by our regions when designing a regional model to take advantage of the power and flexibility of identifiers and their linking capabilities.

7. The ability to create an individual column within the linear programming matrix using "direct entry" is also important. In each of our regions, we have found that there are some prescriptions which cannot be accurately represented using the yield file and yield composite components. In these situations, the direct entry approach allows us to realistically and accurately portray and define both the timing and yields of the activities and outputs which comprise a particular prescription.

In review, we believe that the features provided within FORPLAN allow us to more realistically and accurately describe our regional forests and also represent the real-world operational, environmental and economic considerations within which we operate. Though FORPLAN provides for considerable model definition, we only use what is necessary to address a set of preconceived questions and issues which are important. Used this way, FORPLAN modeling results can be more closely matched to actual timber stands and silvicultural operations with the microeconomic considerations of the region. In addition, using a small set of questions and issues should allow forest planners to focus their attention on the major internal and external issues without getting bogged down in minutiae. In total, FORPLAN has proven itself to be a powerful decision-making tool and has gained in acceptance and use as the preferred modeling method for evaluating forest planning issues at Boise Cascade.

As previously mentioned, a considerable amount of time and money was spent in implementing FORPLAN at Boise Cascade. To successfully implement the model, we were required to modify source code, and design strategies and procedures to better represent our operating environment. The revisions have centered on three major areas. First, several new features to the source code were added to accurately represent the economic climate. These features enhance the financial characteristics of the input requirements of the model, so that we can evaluate our regional timberlands using an investment analysis approach. Two new reports were added to the report writer which summarize important financial and investment information.

Second, the source code was modified to correct several of the known errors as reported in the USDA FORPLAN Users Guide. In addition, we reformatted all output from the matrix generator and report writer modules to meet our reporting needs. Because many of these reports are reviewed by top and middle management, it is crucial that each report is clear, concise, and easy to read. This reduces the need for an intermediate step of pulling numbers together on a piece of paper and having it typed. Instead, the computer can create reports, saving time and costs.

Finally, we have modified some of the logic on how the model works. These modifications have focused on two major areas. First, a set of JCL procedures were designed to adapt FORPLAN within an IBM 370 operating environment. These procedures were structured to maximize the operating efficiency of the model without seriously degrading our total data processing resources during model runs. Because the JCL procedures were rather complex, it was important to make these procedures user-friendly. This was accomplished by storing all information related to the opening and closing of files within a set of procedures transparent to the user. The JCL seen by the user, asked for simple input requirements (e.g., "What is the name of your processing file?").

The second logic modification occurred in the report writer module of FORPLAN. Because of our LP solver and other system requirements, the source code was redesigned to increase the speed of report writer runs by eliminating redundant calculations. As an example, before the code was modified, a typical report writer run took over 6 1/2 hours. With the modifications, this same run now takes less than eight minutes. This increase in efficiency has reduced the costs of a report writer run by 90%. As such, operating regions can now run the report writer as often as needed with minimal impact on other users of the corporate data processing resources.

To help the regions implement our version of FORPLAN, two manuals were developed: (1) a "Users Guide" and (2) a "FORPLAN MODEL EXAMPLE." The "Users Guide" has three purposes:

- To provide a modeling framework which describes the essential components of FORPLAN and shows how these components are related. This framework provides the basis on which a regional model is built.
- To describe how to build a FORPLAN model with emphasis on rules and limits for data input. Examples are provided to enhance user understanding of these model building requirements.
- To recommend several model building techniques which help minimize the costs of model development without sacrificing the comprehensiveness and accuracy of a forest planning analysis.

The "FORPLAN EXAMPLE MODEL" manual is used to describe and show correct data input for a typical regional forest modeling effort.

Where Do We Go from Here?

With the effort spent on FORPLAN and anticipating what new features or requirements our regions would like to see in the model, additional enhancements are being considered. First, we are contemplating restructuring the logic behind use of yield tables to increase the efficiency, in terms of both time and money, of matrix generation runs. In particular, we want to reduce Yield File I/O to provide better utilization of a yield table once it is read into memory.

Second, we have recently acquired the latest IBM version of FORPLAN (Release 10) and would like to merge this release with all our coding changes.

Finally, we are exploring the feasibility of expanding the capabilities of the objective function in at least two ways. First, we want to add additional objectives, such as to maximize cash flow and to maximize PROTC. Second, we are exploring the feasibility for providing users the capability to regenerate the objective function coefficients, in total or in part, without having to make a complete matrix generation run. The goal of all these is to reduce the cost of a FORPLAN model as much as possible, making it more attractive as an analytical tool.

Summary

In summary, both corporate and regional forest planners agree that FORPLAN capabilities allow more real-world influences to be considered than previous timber harvest scheduling models. This is important from an analytical viewpoint, but it can be even more critical from an implementation perspective. If the quantitative analysis cannot be tied back to actual practice, then the results are fruitless. We believe that FORPLAN provides us the capabilities to realistically and accurately describe our regional forests and the internal and external forces which impact our forest plans. We expect that future FORPLAN models will continue to play an important role in the management of the second largest asset Boise Cascade owns -- our timberlands.

British Columbia's Experience with FORPLAN

Lois H. Dellert[1]

Abstract.--Because of British Columbia's land management and resource planning requirements, its approach to modeling, and its priority on resource planning, it has decided not to use FORPLAN. Also, FORPLAN models have proven to be difficult for managers to understand. As FORPLAN evolves and British Columbia circumstances change, it will continue to evaluate the system.

The title of my paper is "British Columbia's Experience With FORPLAN." However, British Columbia is not using FORPLAN, and, based on an evaluation of its suitability, does not intend to use FORPLAN. There are three reasons for this decision:

1. British Columbia's land management and resource planning requirements are different from those in the U.S.A.;
2. British Columbia has chosen a "component approach" to modeling rather than using a single large model; and
3. Given the priority placed on resource planning in British Columbia, the resources are not available to implement FORPLAN.

My paper, therefore, would be better titled "British Columbia's Evaluation of FORPLAN" as it will discuss in more detail the rationale behind each of these three reasons.

British Columbia has successfully used two American planning models, Timber Resource Allocation Method (Timber RAM, Navon 1971) and Multiple Use Sustained Yield Calculation (MUSYC, Johnson and Jones 1979), to provide analytical support for strategic timber supply planning. As there seemed to be parallels in the evolution of forest planning north and south of the border, we were curious about the new American planning model, FORest PLANning model (Johnson 1979), Should British Columbia move on from using MUSYC to using the latest generation planning model, FORPLAN?

Early attempts to acquire and test FORPLAN were severely hampered by two factors. The British Columbia government's computing environment is IBM,[2] and an IBM version of FORPLAN was not readily available. The second factor was lack of information. It was difficult to find out anything about the model. What was heard about it through word of mouth was not encouraging. The impression one got of FORPLAN was of a data-hungry monster whose appetite took person-years to fill, and which regurgitated an incomprehensible solution leaving no option but to accept it as "the optimal." With the amount of bad press FORPLAN was getting, we began to question its usefulness in British Columbia.

The British Columbia Forest Service finally acquired an IBM copy of FORPLAN, version 2, in 1984 and managed to get the model running with the sample data set supplied. However, this did little to help understand the model, because the terminology and planning approach were significantly different from those of Timber RAM and MUSYC with which we were familiar. At that point, the only documentation available to us was a user's guide which was too specific to be of much use in evaluating the model. Because of the frustration this caused, combined with other priorities, FORPLAN was put aside. Interest in FORPLAN was again piqued last December when I attended a short course in Corvallis. Norm Johnson provided excellent instruction and, for the first time, I grasped the concept of FORPLAN. The course, along with the overview documentation, finally provided enough insight to rationally evaluate the model's suitability in British Columbia.

The balance of my paper focuses on this evaluation and the reasons British Columbia decided not to implement FORPLAN.

BRITISH COLUMBIA'S EVALUATION OF FORPLAN

Is FORPLAN a Suitable Model to Meet British Columbia's Land Management and Resource Planning Requirements?

Although FORPLAN evolved from a series of timber scheduling models, it has developed into a land allocation model to meet the specific requirements of American legislation and policies (Iverson and Alston 1986).

Although there are many similarities north and south of the border, there are also several key differences which have an impact on the use of FORPLAN. To evaluate FORPLAN's suitability in British Columbia, our land management and resource planning requirements must be considered and compared with those in the U.S.A.

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[1] Systems Development Forester Planning & Inventory Branch Ministry of Forests and Lands, Province of British Columbia.

[2] The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

British Columbia is Canada's most western province bounded by the 49th parallel to the south, the 60th parallel to the north, the Canadian Rockies to the east and the Pacific Ocean to the west. The total province area is about 90 million hectares (222 million acres), of which more than 90% is publicly owned. Of the total area, 50% is classified as productive forest land and only 25% or 22 million hectares (54 million acres), as defined through our planning process, is operable and suitable for timber harvesting. The total annual timber harvest from this 22 million hectares is about 75 million m^3 (26 million cunits). Harvesting is still primarily located in old growth stands and the age class distribution is predominantly mature with only 8% of the productive forest land less than 80 years old. (British Columbia Forest and Range Resource Analysis, 1984).

The total population of British Columbia is 2.5 million, with fewer than 1 million outside greater Vancouver. There are large tracts of forested land in sparsely populated areas which can be managed primarily for timber. British Columbia's forests are extensive and remote compared with the U.S. South, for example, and are most similar to those of the Pacific Northwest and Alaska.

Responsibility for the management of the forest resource lies solely with the provincial government. Within the province, the mandate is divided between several ministries with the Forest Service of the Ministry of Forests and Lands having the responsibility for timber, range, and recreation from public lands. Other Ministries are responsible for wildlife, fisheries, parks, and mineral development. Although the Forest Service has the dominant position, there is no central land management planning agency or interdisciplinary planning system.

The basic objectives of the Forest Service are established in Section 4 of the **Ministry of Forests Act** and include the forest planning mandate "to:

(a) encourage maximum productivity of the forest and range resources in the Province;

(b) manage, protect and conserve the forest and range resources of the Crown, having regard to the immediate and long term economic and social benefits they may confer on the Province;

(c) plan the use of the forest and range resources of the Crown, so that the production of timber and forage, the harvesting of timber, the grazing of livestock and the realization of fisheries, wildlife, water, outdoor recreation and other natural resource values are coordinated and integrated, in consultation and cooperation with other ministries and agencies of the Crown and with the private sector;

(d) encourage a vigorous, efficient and world competitive timber processing industry in the Province; and

(e) assert the financial interest of the Crown in its forest range resources in a systematic and equitable manner."

Land management and resource planning are less tightly regulated by legislation and procedures in British Columbia than they are in the USA, and British Columbia's resource managers have much flexibility and subjectivity.

Land allocation is carried out in a broad sense by designating land that is best managed for multiple use forest and range as Provincial Forests. Approximately 94% of the public land is designated as Provincial Forest. Land can be withdrawn from a Provincial Forest only if the proposed use provides greater benefits. The benefits of different uses are assessed through localized studies for the areas in question, and the final decision is made by the politicians. No extensive land value/land allocation plans are carried out. Lands available and suitable for timber harvesting are further identified through our planning process. Areas are deleted from the land base for environmental and merchantability reasons. Timber plans are then carried out on the net land base identified.

The public forest land is divided into two different types of management units with timber harvesting rights granted through either an area-based or a volume-based tenure system. Tree Farm Licenses (TFL) are area-based tenures made up of private and public lands. TFLs are managed by private industry and comprise 27% of the total harvest.

Timber Supply Areas (TSA) are managed under a volume-based tenure system and comprise 73% of the total harvest. TSAs are large, varying in size from 500,000 ha (1,235,000 acres) to 7,500,000 ha (18,500,000 acres) and supply timber through volume licenses to as few as 2 to 3 private companies within a single TSA. These companies hold renewable licenses which authorize them to annually harvest a portion of the TSA AAC for as long as their license remains in good standing.

A TSA Plan is developed by the Forest Service for each TSA every five years and includes timber, range, and recreation production targets, management direction and the location of 20-year harvesting areas for each licensee in the TSA. The timber supply analyses carried out to support the TSA Plan are done centrally, unlike the decentralized approach in the U.S.A. Through centralization, flexibility and standardization can both be achieved.

Timber dominates in British Columbia's planning system and other resource values are recognized as constraints on timber harvesting. Timber harvesting plans are referred to other resource agencies for review and conflicts are normally settled through consultation and negotiation at a local level.

Considering these differences between British Columbia's and the U.S.A's requirements for forest planning, is FORPLAN a suitable model to carry out resource planning in British Columbia? As public concern and demand from other resource uses increases and our land management requirements change, British Columbia may evolve to use a FORPLAN land allocation approach; however, until that time, implementation of FORPLAN as a model to support land allocation and resource planning decisions would not be appropriate.

Is the FORPLAN Approach of a Large Single Model Desirable in British Columbia?

Although FORPLAN would not be used in British Columbia as a land allocation model, could it be used for timber planning? Because a major strength of FORPLAN version 2 is its flexibility to model many different problems, a British Columbia formulation probably could be developed using FORPLAN's framework. But before formulating a FORPLAN model, we would first have to determine how we could use it, where it would fit into our planning system and whether it was consistent with our modeling approach.

A model, by definition, is an abstraction of reality. Its usefulness as a decision making tool comes from its ability to simplify a complex process so that a manager may be better able to understand that process. In building a model, the balance between complexity and simplicity must be considered. If a model is too complex it may not be understandable; if it is too simple, it may not be relevant. The balance can be difficult to achieve as managers tend to want the model to make decisions and push for it to be as real as possible. This usually means a large, complex model with much detail. The modeling exercise can become more important than the decision. In British Columbia there is continual pressure from the managers to include more and more detail and many interactions in one model. This provides a challenge for the model builders to develop a model that the managers will accept, which is relevant but still understandable. Can a model be developed which incorporates all the detail and complexity requested and still be understandable? FORPLAN is an example of a model which was built to meet managers' requirements.

The FORPLAN approach of one large model which brings together many forest resources and attempts to model their interactions at once has tipped the balance between complexity and simplicity. In its attempt to model every interaction--to be very realistic-- comprehension has been forfeited. Model results must be understandable to the manager, who is the decision maker. The FORPLAN approach to model a very complex problem is admirable; but are FORPLAN results understandable? Are they interpretable? Are they used as support for decision making, or do they make the decision?

Most modelers understand that a model only supports decision making; but is this understood by the managers? If so, how can they use FORPLAN results as an aid to decision making when the model is very complex and the solutions difficult to interpret? To truly use a model as a support for decision making, it must be well understood.

If the model is large and complex, as FORPLAN can be, the model can easily be mystified and the solution either taken as given or discounted. In one case there is danger that the linear programming solution is taken as the "optimal" solution which must be adhered to as it is perceived to be the best. How many times have you heard, "but the model said..."? Conversely, in the other case if the results of an analysis are not in line with perception or local intuition, and if the modeling process is viewed as a large black box, the model solution will not be accepted willingly. In both of these cases the model provides little help to managers. This was expressed as an "information and understanding gap" and identified as a "barrier to planning" in the Ottawa National Forest (Voytas 1986).

This problem of comprehension could be partially overcome through education, but the education task becomes formidable because FORPLAN is a complex model, and the public as well as the forest managers must be involved. Even if the decision makers and the public understood how FORPLAN worked, could they or anybody else intelligently interpret a complex FORPLAN solution?

Simple problems can be formulated, because FORPLAN is not a really single model, but a framework within which many models can be formulated. Experience shows that an analysis usually reaches the limits of a model, and that if the capacity and capability of the model are expanded the analysis grows to that new limit. It is not the user of the tool or the manager who will usually volunteer to keep the analysis simple but the model which, through its limits, forces simplicity. The model-developers have a responsibility to build understandable models.

The need for comprehension becomes very important because resource planning is not limited to biophysical and economic criteria, which can be modeled, but includes much socio-economic concerns which require a human element. Analytical techniques such as FORPLAN cannot provide the means to resolve resource management issues, but simply provide sharper focus for decision makers. A planning process is required that will provide a framework which permits the use of models as aids and includes a large degree of human input and decision making throughout the process. As a District Ranger from White River National Forest stated, "there is always an ultimate limit to the value of a FORPLAN solution in multiple use management no matter how sophisticated we chose to make our model" (Troyer 1986). Analyses must be understood by the decision-makers in order that the results can be used intelligently and non-quantifiable values can be incorporated into decision making.

British Columbia has decided to pursue a "component approach" to modeling. Within a planning framework, several models, processes or systems, provide support for decision making. The components span several levels of planning and provide the ability to assess many resource use and timber issues. The focus is on the planning process and not on the planning model.

An example of this component approach is illustrated in TSA Planning. Timber supply analyses for TSAs have two components: long-term harvest projections leading to the determination of an Allowable Annual Cut (AAC) and selection of an overall management direction; and the geographic location and scheduling of 20-year harvesting areas for each licensee within the TSA. A component is envisioned which will be geographically specific and provide for the allocation of harvest for a 20-year period to various licensees within the TSA. The short-term strategies developed then would be evaluated for their sustainability by linking to a separate long-term harvest projection model or models. The two components provide for a 20-year time frame, geographic resolution, and long-term assessment resulting in a plan which is relevant and implementable without foregoing detail or a long-term view.

Working against the component approach are the difficulties in achieving linkages between the components.

Linkages between the short-term harvest allocation and long-term harvest projections and between land allocation and timber planning, for example, have been difficult to achieve and pose challenges to modelers. Innovation is required in obtaining these linkages; the modeling effort should be directed here.

When we first looked at FORPLAN we were excited about the potential to link the short and long-term aspects of timber supply planning in one model formulation rather than using separate models. The two features of FORPLAN that were of most interest were the ability to specify variable period lengths and the use of allocation zones to provide geographic resolution. These features could provide the capability to include a detailed, geographic specific 20 year "front end" linked directly to a less detailed long-term "tail end." This would provide the resolution required for 20 year planning and the linkage required to ensure long-term objectives of sustained yield. With closer review, we realized that FORPLAN would not only need variable period lengths, but also would require the specification of varying geographic detail. The overhead of maintaining the geographic resolution required (500 to 2,000 planning cells) throughout the whole planning horizon would be too high. We retreated from the concept of one model to do both short and long-term planning and are now looking for two separate but linked approaches.

FORPLAN could be used to carry out long-term harvest projections, but is it the best choice? As the long-term aspects of the plan are de-emphasized, a simpler model, such as MUSYC, may be more appropriate and is already in use.

FORPLAN also could be used to carry out the 20-year allocation; but does it allow for sufficient geographic resolution? Can it be linked with a geographic information system and can it be linked to a long-term projection model? These questions for the most part have been left unanswered, because FORPLAN has not been used in this manner and would require much more detailed investigation and research.

Perhaps FORPLAN could change its focus and provide a basic framework with which other components, such as a fire and pest model, geographic information system, or a timber allocation model could be linked. British Columbia would be very interested in any future efforts to simplify FORPLAN and to link it with other models, systems and levels of planning.

Could FORPLAN Be Implemented in British Columbia?

The ability to implement FORPLAN was an important consideration in our evaluation as it directly relates to the model's success. Our evaluation considered many factors, technical and human.

The Formulation of a British Columbia Model.

Before using FORPLAN operationally, a major research project would have to formulate a British Columbia problem, link with our data preparation systems, and train the analysts and managers. Until recently, the Forest Service's planning systems development team consisted of one forester. This team soon will be expanded to include one other forester and a systems analyst; however, without additional resources, the implementation of FORPLAN would use 100% of our development resources for at least 1 year. Considering other priorities, the Forest Service could not afford to expend all its resources on FORPLAN.

Staff and Expertise to Use FORPLAN

The planning resources in the Forest Service consist of 12 staff in Victoria, 3 in each of 6 Regions and 1 in some of 46 Districts for a possible total of 76. The total operating budget is less than $1 million. That works out to about 1 planner and $10,000 for every 1 million m^3 (350,000 cunits) harvested annually.

Hands-on experience using forest planning models is limited to six staff in Victoria. Knowledge of FORPLAN in British Columbia is limited to myself, one consultant firm and a graduate student at the University of British Columbia. Our understanding of FORPLAN is general and includes very little hands-on use. Because of FORPLAN's complexity, a major commitment would have to be made to increase our knowledge pool and to educate and train both the analysts and the managers to ensure successful implementation. Limited resources, other priorities and lack of expertise severely hamper our ability to do this.

Computing Environment.

The British Columbia government's computing facility is IBM. Although several IBM versions of FORPLAN have been released, IBM compatibility does not appear to be a high priority of the USDA Forest Service. We would require full support for IBM compatibility before implementing FORPLAN to ensure full support of the model.

Documentation

Documentation of FORPLAN has been slow. However, documentation now exists and FORPLAN appears to be well supported. Hopefully the documentation can now keep up with further development as it is essential for external users who don't have the benefit of internal, informed support and networks.

Data Requirements

The data requirements to use FORPLAN can be enormous. Although we have an excellent forest inventory, data for resource values other than timber are difficult to generate as much of the information is not quantified or compatible. It would take a large allocation of resources and a long time to generate much of the information required.

Considering all of these factors, along with the complexity of FORPLAN, the implementation of FORPLAN in British Columbia would be a formidable task.

SUMMARY

The Forest Service has chosen not to implement FORPLAN; but we are continuing to assess FORPLAN for its suitability in light of projected changes in British Columbia's modeling requirements and in the evolution of FORPLAN.

British Columbia's requirements for resource planning models are changing. Resource planning is evolving in British Columbia as public awareness of and demand for other resource values and better management increases. However, given the differences outlined in this paper, resource planning in British Columbia may or may not evolve in the same manner as the in the USA. As our requirements change, we will continue to evaluate American resource planning models, including FORPLAN, for their suitability.

We are curious about the future of FORPLAN. If it can be simplified, easily linked with other planning models including a geographic information system to become part of an overall planning system, and can be supported on an IBM system, it may provide a useful planning tool for British Columbia.

Although British Columbia has not implemented FORPLAN, we have learned much from it which will help us to develop and use resource planning models. I hope that my comments have provided you with some insight and will help you in future modeling endeavors. We will be following FORPLAN's evolution with interest.

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The North Carolina State University Experience with FORPLAN: Software Transfer and Example Of Use

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Abstract.--NCSU required the use of FORPLAN software for several management research projects. FORPLAN software was obtained through the University of California, Berkeley. Several steps are discussed on how FORPLAN was transferred for use at NCSU. The first applications of FORPLAN at NCSU, a national planning model for Jamaica, is also discussed.

The print out of the FORPLAN code requires 0.2 cubic feet of paper, weighing in at 9.7 lbs. It would take a loblolly pine seed in average soil about 16 years to make the wood for this print out. No big deal when compared with the amount of fiber in the national forests. However.....

In the summer of 1985 the Department of Forestry at North Carolina State University acquired a tape containing FORPLAN software from the University of California, Berkeley (UCB). At UCB FORPLAN is running on the IBM-Conversational Monitor System (CMS), and because one of our campus computer systems used IBM-CMS, our hopes were high that we would soon be running FORPLAN. On the first day the program was loaded into CMS, FORPLAN could be started using the EXEC (execution) language program supplied by UCB with the rest of the FORPLAN files. On the same day our problems began.

On the NCSU CMS system the standard secondary memory allocation is less than one cylinder. FORPLAN required 35 cylinders of space. This results in quite an expense just to store the model.

The EXEC program was failing on some system software differences between UCB's and NCSU's version of CMS. These needed to be reconciled.

The most serious problem was that the solution software required for this version of FORPLAN is MPSX. Not only was this software not on the CMS system, but the campus had discontinued its use on all systems in favor of another large scale LP solution package. However, there was a version of MPS kept on another IBM computer system using the Time Sharing Option (TSO) operating system. The original install tape for MPS was located but because of age (original installation around 1975) the magnetic fields on the tape had deteriorated beyond the background noise level. The tape could not be read. At this point we considered two options. Either we could: (1) generate the matrix on CMS and send the matrix file to TSO, through a filter to remove discrepancies between MPS and MPSX, solve the problem on MPS, send the results through an output filter, and back to CMS to the report generator; or (2) we could move FORPLAN to the TSO system, and do all the calculations on one system. Because of the size of the problems we were working with, we felt it would be best to do all work on one system. Notice that one possible option was not included: buying or leasing MPSX. The cost of MPSX was around $17,000 and our initial budget to get FORPLAN running was less than $10,000. In hind sight, it may have been less expensive to buy MPSX and load it onto CMS.

During the summer and fall of 1986, we installed FORPLAN on the TSO system for the North Carolina State University School of Forest Resources. This document contains two major sections the first describes the strategy and specific steps taken while installing FORPLAN and the second discusses an application in planning Jamaica's forest resources.

INSTALLATION OF FORPLAN

This section has two parts. The first outlines a general strategy for installing any program like Forplan and the second section details the specific steps taken while installing FORPLAN at NCSU.

General Strategy for Installing FORPLAN

There are at least four major steps required when installing a program like FORPLAN. The first step is determining whether available computers have the hardware needed to execute the program. After finding a computer system, the second step is moving the files with the source code onto that computer system. Once all the files with the source code are on the computer system, the third step is translating the source code into executable code. After supplying the computer system with executable code, the fourth step is supplying the executing program with data in a usable format. Each remaining paragraph, in this section, provides succinct elaboration on each of these four steps.

Before acquiring a computer program, determine whether the available computers have enough hardware to allow the program to execute. The hardware of a computer system consists of a central processing unit, an arithmetic/logic unit, random access memory and peripheral input/output devices. Distributors of programs usually provide a list of the hardware required to allow the program to execute. For example, a program requiring 5 megabytes of random access memory will not execute on a computer which has only 640 kilobytes of random access memory. Similarly, a program requiring 2 tape drives, will not execute on a computer that has no tape drives. A computer system's capacity to store and access information, using devices like fixed disks and tape drives, may not only preclude execution of a program, but may not be sufficient to store the program itself.

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After finding a computer system capable of storing and executing the program, the source code files are then placed into the computer system. The source code files are ASCII files which hold only information which is readable by humans. In other words, these are the files that computer programmers have entered using a keyboard. Once again, these files are written in English. These files are transported using media that the computer system supports. For example, a tape may be sufficient, given that the computer system, not only has a compatible tape drive, but also is able to read the format in which information is stored on the tape. A tape may not be the most convenient medium for moving files to a computer system. For example, the capacity to transfer files over a telephone line is sometimes more convenient.

After the source code has been stored on the computer system, the next step is to translate the source code into executable code. Files containing executable code cannot be read by people, but they can be read and used by computers. Requirements for consolidating source code into executable code vary depending on the complexity and structure of the computer program. For example, a simple program may only require one compile step, one link step and one go step. Where the compiler translates source code into an object module, the linker translates an object module into a load module and the go step loads and executes the load module. However, complex programs, such as FORPLAN, may require several compile and link steps before the go step. Each file holding source code is first translated into an object module, and second, each object module is cross referenced, by the linker, and stored, as a load module, in a library of load modules (this library is usually stored as a partitioned data set). After all source files have been stored as load modules, the computer program is ready for execution.

After supplying the computer system with executable code, data must be made available in the format expected by the program. Because data can be accessed using any one or more of several devices, it is necessary to know which devices the computer program expects to use. Additionally, it is necessary to know the precise method for presenting data to the computer program. For example, it may be necessary to provide data which establishes initial conditions before presenting that data pertinent to a particular problem. Also, the physical arrangement of data may vary from one computer program to the next. For example, the computer program may require that the data consist of a certain number of lines and that each line be presented in a particular columnar format.

When an adequate computer system has been supplied with an executable program and the data expected by that computer program, the process of installation is finished. When installation is finished, the process of use and maintenance begins. Using a program can be a formidable task simply because the data required may be expensive to supply, alter and maintain. The costs associated with using a program almost always overshadow the costs incurred while installing that program.

Adapting the General Strategy To Install FORPLAN

Having established the events required to install a program like FORPLAN, the following outline reconciles that general strategy with the steps taken during installation. Each of the numbered steps, in the following outline, corresponds to an event which occurred while installing FORPLAN. As each objective in the general strategy is accomplished, it is noted with commentary.

1. Reconcile hardware requirements with available computer system.

   The tape with the source code needed to install FORPLAN were written using the UCB equivalent of the IBM CMS TAPE DUMP command. Therefore, a computer, at NCSU, capable of reading this format was required. Additionally, FORPLAN produces files that are used as input to the IBM Mathematical Programming System, then Forplan reads and processes the output of the Mathematical Programming System. So a computer capable of operating MPS with Forplan was another requirement. Finally, Forplan requires a minimum of 2 megabytes of random access memory, a tape drive and a considerable amount of space on a disk pack.

   Having established the requirements, the next step was to evaluate the capacity of the available computer system. The NCSU computing center operates a CMS system capable of reading the tape created at UCB. The Triangle Universities' Computing Center (known as TUCC) operates a computer system capable of executing both MPS and Forplan and also has a version of MPS available.

   Having found a computer system to match the requirements, the next step was to move the files with the source code onto the computer system.

2. Receive tape from University of California at Berkeley

3. Move files from tape onto disk on CMS

4. Move subroutines from MACLIB to individual files on CMS

5. Move individual files from CMS to TSO

The source code had been stored, on tape, in a file called FORPLAN MACLIB. After loading the tape on the tape drive, the command, "TAPE LOAD FORPLAN MACLIB D1," moved the file from the tape to the D-disk. A list of files in the Maclib was displayed using the command, "MACLIB MAP FORPLAN MACLIB D1." Files stored in a CMS Maclib can be moved from the Maclib to the Punch machine using the command, "PUNCH FORPLAN MACLIB D1 MEMBER (membername)", where membername is the name of one of the files in the Maclib. The Punch command takes the files out of Maclib format and converts it into ASCII format. After moving the member from the Punch machine to disk, the file can be further processed. In our case, further processing meant moving the files from CMS at the NCSU Computing Center to TSO at the Triangle Universities' Computing Center (TUCC). The files were transferred using the electronic mail system.

Having supplied the computer system with the files containing the source code, the next step was to translate the source code into executable code.

6. Produce hard copy of the source code
7. Prepare list of all subroutines and calls to subroutines
8. Prepare files for compilation and linkage
9. Compile, link and store files in a PDS at TUCC
10. Back up all files and the PDS on tape at TUCC

Because the Forplan program consists of more than 230 separate subroutines, it required as many compilation and linkage steps. Subroutines which referred to no other subroutines were the first procedures compiled and stored in a partitioned data set. Remaining procedures were compiled and cross referenced with routines already in the PDS.

Having supplied the computer system with executable code, the last objective was to supply data to the executing program.

11. Prepare list of all read, write and format statements
12. Match the instructions in the user's manual with the read, write and format statements
13. Establish files required to execute Forplan

Files containing the source code were processed to produce a list of all Read, Write and Format statements. These statements were cross referenced with the user's manual to determine which files are required by each module of Forplan.

14. Write command procedure to coordinate the execution of Forplan's modules and MPS

This step is unique to installing Forplan. The Forplan program is actually a set of separate programs, the execution of which, must be coordinated. Results are passed, using files, from one module to the next. A command procedure coordinates the execution of modules depending on the information stored in the files that are passed from one module to the next.

FOREST PLANNING MODEL FOR JAMAICA

The initial use of Version 2 FORPLAN at North Carolina State University is to examine the current pine lumber import substitution strategy of Jamaica. In the early 1960's the Forestry Department of Jamaica began establishment of *Pinus caribaea* var. *hondurensis* (PCH) plantations in the eastern and generally mountainous portion of the island. The objectives were to provide watershed protection and to substitute for lumber imports, primarily from the southeastern United States and Central America. In 1986 there are about 10,000 hectares in pine plantations on government lands (FIDCO 1986). A smaller area of pine plantations also exist on private lands. About 60,000 additional hectares in the eastern portion of the island have soils suitable for PCH (FIDCO 1986).

In 1978 a state-owned company, Forest Industries Development Corporation (FIDCO), was formed with the "objective of developing the potential for commercial forestry and forest industries in keeping with the nation's strategy of import substitution, job creation, and optimum land utilization" (FIDCO 1979). Harvesting and sawmill operations for lumber production began in 1979. In 1985 FIDCO produced 4.8 million board feet of import grade lumber, representing 19% of total consumption of this grade. Inferior grades of lumber and treated posts are also produced.

Soil and rainfall conditions permit high growth rates, between 15 and 27 cubic meters per hectare per year on a 20-year rotation. Also, the FIDCO sawmill is running on a single shift basis so that production could be expanded with an increase in log supply. However, about 75% of the suitable forest land requires skyline harvesting. In addition, both coffee and mixed agriculture compete for land use over much of the area, particularly following forest road development. The compatibility of forest plantation wood production and watershed management is also a significant issue for those lands near Kingston.

Jamaica's location, and favorable credit arrangements in recent years, account for the current role of the United States as the major supplier of coniferous lumber. However, the long-term trend of total consumption of import grade coniferous lumber has declined over the past 20 years, -0.8% per year (External Trade Bulletins, 1966-1985). Constant real income per capita, increasing import supply prices (1.2% per year), and increases in duties contribute to the decline. In April 1986 the effective duty on lumber imports was increased from 9% to 27% which should further reduce consumption and imports.

Policy Issues

The principal policy issue in this context is that of determining the appropriate land use strategy given current knowledge of production possibilities and factor and output price expectations. The three graphs in figure 1 illustrate the conceptual model for determining the lumber production equilibrium in a static context. The graphs are identical except for the domestic supply schedules, S_D, S_I and D_E represent the perfectly elastic import supply and export demand schedules respectively. In the upper graph Q_d should be produced domestically, and Q_t -Q_d should be imported. In the bottom graph the equilibrium is one of autarky so that domestic production equals consumption.

The primary objective of this study is to test the hypothesis that the appropriate long-term land use strategy is one in which a combination of imports and domestic production provides the quantity demanded at the import supply price adjusted for duties and distribution costs. Additional objectives of the study are to show the import and domestic supply quantity schedules in the short-term and to test the sensitivity of the results to alternative price and policy expectations.

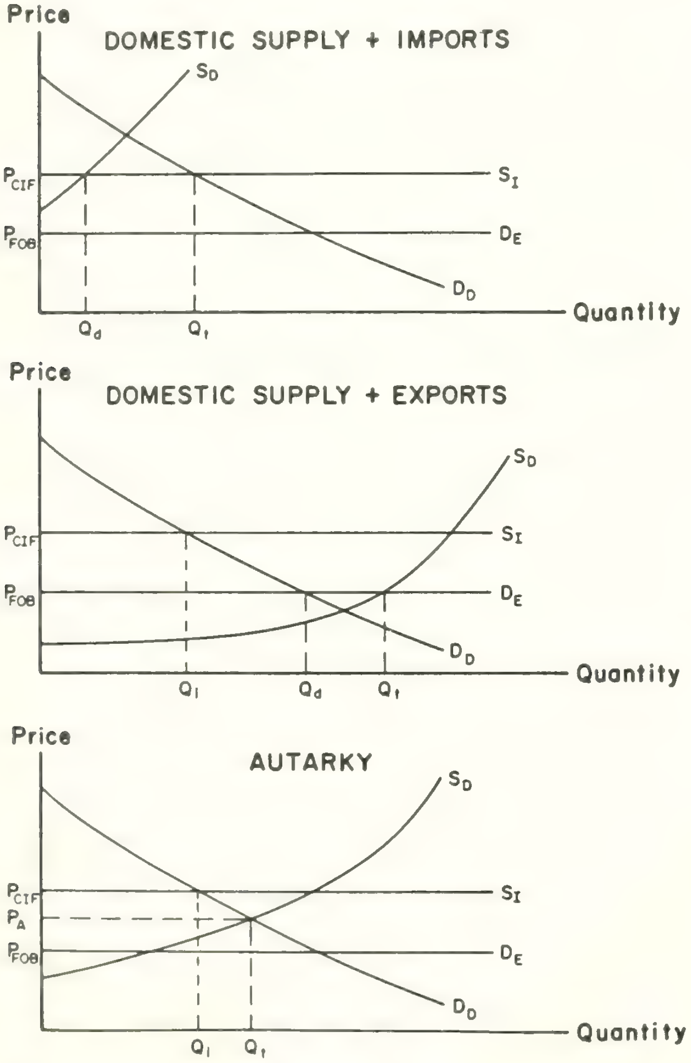

Figure 1.--Conceptual import substitution - export promotion model.

Linear Programming Model

The harvest scheduling-linear programming (LP) model is convenient for examining this problem, particularly given the flexibility of Version 2 FORPLAN for representing alternative investment decision variables. Unlike the static representation shown in figure 1, the model permits the specification of domestic wood supply curves for alternative time horizons.

The base case computer run of this problem will assume that the optimal solution includes at least some importation of lumber in each period of the planning horizon (top graph fig. 1). However, if all demand is met by domestic production in at least one period for the base case, another case may be run to portray the other equilbria possibilities using the price-quantity options in FORPLAN. In this case the appropriate price-quantity locus is P_{CIF} to the point of intersection with D_D, D_D to the point of intersection with D_E, and P_{FOB} for greater quantities.

Decision Variables

The decision variables, objective function, and constraints for the problem are given in table 1. There are three categories of decision variables: land use, capacity installation, and lumber importation. The latter two categories are conceptualized as special "analysis areas" to conform to the Version 2 FORPLAN input structure.

Land Use

Table 2 gives a schematic representation of the prescription and timing choices to be considered for each analysis area over the chosen planning horizon of thirty-eight years. The first part of the table gives the prescription-timing choices for the land use decision variables.

There are four vegetation categories: PCH, native vegetation, coffee, and mixed agriculture. Based on land classification by the Ministry of Agriculture, there are three long-term land capability classes: forest, coffee, and agriculture (Vernon 1959). The rate of conversion from the current land use to the long-term land capability class can be modified by specifying constraints or limiting the prescription-timing choices for a given current land use. The land use capability classification will be used to determine what alternative land uses are permitted for a given current land use.

For pine management the principal identifiers for differentiating analysis areas are: age class, site index class, stocking, harvesting system, transport distance, roading status, and ownership class. Pine management treatments are based on even-aged management with no thinnings. The timing choices permit clearcuts between seventeen and thirty years of age (table 2).

Table 1.--Linear programming lumber import substitution model.

Decision Variables

U_{ijkl} = existing hectares of pine age class i, yield class j, alternative use class k, managed with prescription-timing choice l

W_{ikl} = existing hectares of native hardwood vegetation of yield class j, alternative land use class k, managed with prescription-timing choice l

X_{jkl} = existing hectares of coffee (same subscript definitions as above)

Y_{jkl} = existing hectares of mixed agriculture land use (same subscript definitions as above)

Z_{gm} = volume of lumber in use class g, imported in period m

Q_{fil} = operating units of standard capacity of processing function f, depreciation status i, installed and depreciating with timing choice l

Objective Function

$$\text{Maximize NPV} = D'_u U + D'_w W + D'_x X + D'_y Y - D'_z Z - D'_Q Q$$

D_u, D_w, D_x, D_y = stand or crop level net present values per hectare at the start of the planning horizon (excluding capital costs in D_Q)

D_z = discounted CIF price plus domestic handling cost per unit volume of imported lumber

D_Q = discounted capital costs per unit of capacity (purchase, installation, maintenance, and salvage)

Constraints

1. Land Area
   a. Total hectares in solution equals total hectares available
   b. Prescription-timing choice assignments are consistent with management control capabilities and land use policy
2. Import Grade Lumber Demand (for each period)
   a. Imported lumber of grade g is less than or equal to lumber demand at the duty inclusive import supply price
   b. Domestic lumber production of grade g is less than or equal to lumber demand at the import supply price, exclusive of duties
   c. Domestic lumber plus imported lumber supply is greater than or equal to total lumber demand at the duty inclusive import supply price
3. Coffee Supply

   Total coffee produced in each period, both within and outside of the model area, is less than or equal to the Coffee Marketing Board quotas.
4. Lumber and Kiln-drying Capacity
   a. Installed capacity in each period is greater than or equal to the amount required for domestic lumber production
   b. Increases or decreases in installed capacity between periods are within levels consistent with capital costs per unit of capacity.
5. Financial

   Financial cash flow of the forest industry is consistent with financial commitments and funds allocated to that sector

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Table 2.--Schematic representation of prescription-timing choices (treatment codes) for base case.

First identifier	Second identifier	Third identifier	Prescription number	Period:	1	2	3	4	5	6	7	8	9	10	11	12
				Year:	1-2	3-4	5-6	7-8	9-10	11-14	15-18	19-22	23-26	27-30	31-34	35-38
Initial vegetation	Permissable land use	Best alternative land use			Land use decision variables											
PC	F	HF	1		CC	RP						CC/RP				
			2		CC	RP						CC	RP			
								etc.								
			3			CC	RP					CC	RP			
			4			CC	RP						CC/RP			
								etc.								
			5		NV											
			6		CC	NV										
			7			CC	NV									
								etc.								
PC	C	CO			Prescription nos. 1-4 etc.; 5; 6-7 etc. plus :											
			8		CC	RC										
			9			CC	RC									
								etc.								
PC	A	MA			Prescription nos. 1-4 etc.; 5; 6-7 etc. plus:											
			10		CC	RA										
			11			CC	RA									
								etc.								
HF	F	HF			Prescription nos. 1-7 etc. except no restriction on maximum clearcut age											
HF	C	CO			Prescription nos. 1-4 etc.; 5; 6-7 etc.; 8-9 etc. except no restriction on maximum clearcut age											
HF	A	MA			Prescription nos. 1-4 etc.; 5; 6-7 etc.; 10-11 etc. except no restriction on maximum clearcut age											
CO	F	PC			Prescription no. 5 plus:											
			12		RP						CC	RP				CC/RP
			13		AC	RP						CC/RP				
								etc.								
			14		AC	NV										
			15		AC		NV									
								etc.								
CO	C	PC			Prescription nos. 5; 12-15 etc. plus:											
			16		AC											
CO	A	MA			Prescription nos. 5; 12-15 etc. plus:											
			17		RA											
			18		AC	RA										
								etc.								
MA	F	PC			Prescription nos. 5 & 12 plus:											
			19		AA	RP						CC/RP				
			20		AA		RP					CC	RP			
								etc.								
			21		AA	NV										
			22		AA		NV									
								etc.								
MA	C	CO			Prescription nos. 5,12,19-20 etc., 21-22 etc. plus											
			23		RC											
			24		AA	RC										
								etc.								
MA	A	PC			Prescription nos. 5,12,19-20 etc., 21-22 etc. plus:											
			25		AA											

(Continued)

Table 2.--(continued).

First identifier	Second identifier	Third identifier	Prescription number	Period: Year:	1 1-2	2 3-4	3 5-6	4 7-8	5 9-10	6 11-14	7 15-18	8 19-22	9 23-26	10 27-30	11 31-34	12 35-38
Processing function	Depreciation status	Product grade			Processing and lumber importation decision variables											
SW	EC	-	26		SV											
			27			SV										
								etc.								
			28										SV			
			29										SV/IN			
SW	FC	-	30		IN									SV		
			31		IN										SV/IN	
			32			IN									SV	
			33			IN									SV	IN
			34				IN									SV
			35				IN									SV/IN
								etc.								
KD	EC	-	36		SV											
			37			SV										
								etc.								
			38								SV					
			39								SV/IN					
KD	FC	-			Prescription nos. 30-35 etc.											
-	-	NS	40		no import "treatment"											
			41		IM											
			42			IM										
			43				IM									
								etc.								
-	-	ST			Prescription nos. 40-43 etc.											
-	-	OP			Prescription nos. 40-43 etc.											

RP = site prepare and regenerate to pine
RC = site prepare and regenerate to coffee
RA = site prepare and regenerate to agriculture
CC = clearcut pine or native hardwood vegetation
NV = initiate fallow management

AC = continue coffee management
AA = continue agricultural management
IN = install processing capacity
SV = salvage depreciated capacity
IM = import lumber

PC = pine
HF = native vegetation
CO = coffee
MA = mixed agriculture

F = forestry
C = coffee
A = agriculture
SW = sawmilling
KD = kiln-drying

EC = existing capacity
FC = future capacity
NS = non-structural
ST = structural
OP = other import grade

Native vegetation management is considered as fallow management in which the only management inputs are those for supervision and protection from encroachment by other land uses. Returns from this essentially wilderness and watershed management emphasis are not considered for the base case.

Returns from coffee and mixed agriculture are based on their expected annual land rents. For coffee, land rent is determined primarily on the length of the coffee rotation and the grade of the bean, Blue Mountain or Lowland coffee. For mixed agriculture, land rent is based on the net returns from the principal crops in each management district.

For all land use prescriptions in the base case, only one conversion from one type of vegetation to another is permitted during the planning horizon. For example, conversion from pine to mixed agriculture and back to pine is not portrayed as a prescription option (fig. 2).

Capacity Installation

Capacity installation decision variables permit the addition of additional capacity as part of a domestic lumber production strategy. Identifiers are used to distinguish capacity installation "analysis areas." In addition, other identifiers are used to specify the depreciation status and capacity function. Depreciation status identifiers are existing capacity and capacity installation during the planning horizon. Capacity function categories are sawing and kiln-drying. Prescription-timing choices for each analysis are indicated by prescription numbers 26 - 30 in figure 2.

Lumber Importation

The possibility of lumber importation is portrayed using different analysis area identifiers for each of the three imported lumber product grades: non-structural (pattern stock), structural, and other prime (dimension). Prescriptions permit the importation of various combinations of these grades for any period during the planning horizon, numbers 40 - 43 in figure 2.

Objective Function

The objective function for the problem is to maximize the discounted return from the land resource and other existing assets given the existing and expected production relationships and policy constraints. The principal activities and outputs for the decision variables are given in table 3. Activities under the heading of "developed land management" apply to all land use prescriptions except for native vegetation management. These activities would normally be subject to coordinated allocation scheduling in a Version 2 FORPLAN formulation. However, the lack of spatially detailed data and the present model's use for strategic rather than operational planning eliminate this option for the base case computer run.

Using identifiers and qualifiers the per unit activity/output amounts can be varied depending upon conditions. For example, logging productivity per crew day for pine harvesting will be related to volume per hectare and per tree. For sawmilling, lumber recovery rates and sawmilling productivity per shift operating hour will depend on log small end diameter.

Common economic cost and return information will be used to input market prices and shadow price conversion factors to internally calculate economic costs and values (Squire and van der Tak 1981). For domestically produced lumber of import grade, the CIF price of the lumber plus domestic handling charges is used as the "market price" rather than the protected price reflecting duties and import restrictions. Inferior lumber grades and residues produced as by products will be valued for the base case using recent sales prices and assuming perfectly elastic demand.

Constraints

A brief explanation of the constraints for the problem is given in table 1. The second type of land constraint (no. 1b) refers to the categorization of the land base into three ownership categories in terms of forest management control: fee simple or long-term lease, current rotation lease, and private ownership.

The lumber demand constraints (no. 2) assume the existence of a government controlled pricing policy which requires domestically produced lumber of import grade to be sold for the import supply price excluding duties. This is consistent with a maximization of consumer plus producer's surplus in the presence of import duties.

Coffee supply constraints (no. 3) are necessary to assure that coffee quantities and prices are consistent with International Coffee Board quota arrangements. In recent years Jamaican production has been about 75% of its allowable quota (Marshall 1985).

The second type of lumber processing constraints (no. 4b) is to adjust for the non-integer formulation of the problem. Financial constraints (no. 5) will not be used in the base case run of the model. However, these constraints may be important given the quasi-private nature of domestic lumber production in Jamaica.

CONCLUSION

FORPLAN can be relocated to other computer systems if the system has the hardware and software required for its use. The major hurdles in relocation are compiling and linking the separate subroutines of the program and in writing the job control statements to execute the program and the amount of resources the program uses. Software requirements are MPSX linear programming package, and a general purpose FORTRAN compiler. Hardware requirements are a minimum of 2 megabytes of RAM, at least one tape drive, and sufficient disk space.

The effort to make a multiple resource planning model has made FORPLAN Version 2 flexible enough to allow

Table 3--Principal activities and outputs.

Activity or output	Units
Developed land management	
Construction, access roads	km./ha.
Construction, harvest roads	km./ha.
Upgrading, access roads	km./ha.
Upgrading, harvest roads	km./ha.
Road maintenance	km./ha./yr.
Machine hours (mh.)	
Road construction	mh./km.
Upgrading	mh./km.
Maintenance	mh./km.
Pine Management	
Silviculture, labor input (by year in the rotation)	man-days/ha.
Silviculture, management overhead	$/ha./yr.
Logging, crew-days (cd.)	cd./cu.m. logs
Logging, machine hours	mh./cd.
Logging, machine operating expenses	$/mh.
Logging, machine capital costs	$/mh.
Logging, labor expenses	$/cd.
Logging, miscellaneous expenses	$/cd.
Logging, management overhead	$/cd.
Logging, post production expenses	$/ha. harvested
Construction, planned skid trails	km./ha. harvested
Machine hours, planned skid trails	mh./km.
Log transport, cubic meter-km.	km./cu.m. logs
Post transport, # post-km.	km./post
Log transport costs	$/cu.m. - km.
Post transport costs	$/post-km.
Sawmill, shift operating hours (sh.)	sh./cu.m. logs
Sawmill, operating expenses	$/sh.
Sawmill, management overhead	$/sh.
Head office administration,	
Plantation development	$/ha. mgd.
Logging and sawmilling	$cu.m. logs
Transfer payments,	
Plantation development	$/ha. mgd.
Logging and sawmilling	$/cu.m. logs
Log volume harvested (V15IB)	cu.m./ha.
Treated posts	# / ha.
#2 and better, dressed lumber, > 10'	
Non-structural, e.g. pattern stock	nominal cu.m./ha.
Structural	nominal cu.m./ha.
Other, e.g. dimension	nominal cu.m./ha.
#2 and better, rough lumber, 6' & 8'	nominal cu.m./ha.
#3 and #4, rough lumber, random lengths	nominal cu.m./ha.
Bark	cu.m./ha.
Sawdust, chips, slabwood	cu.m./ha.
Shavings	cu.m./ha.
Other land management	
Coffee land rent	$/ha./yr.
Coffee production (by yr. of rotation)	kg. green beans/ha.
Mixed agriculture land rent	$/ha./yr.
Native vegetation protection	$/ha./yr.
Processing capacity	
Capital costs (by year from installation)	
Sawmill	$/std. hour of capacity
Kiln-drying	$/cu.m. of lumber
Standard units of capacity (by year from installation)	
Sawmill	std. hrs./std. hr. installed
Kiln-drying	cu.m./cu.m. installed
Lumber importation	
Non-Structural grades	$/nominal cu.m.
Structural grades	$/nominal cu.m.
Other grades	$/nominal cu.m.

many different matrix structures. As a natural resource planning tool the full range of its use has not yet been explored.

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Use of FORPLAN by Industry and State and Provincial Governments: Discussion Paper

Thomas R. Mitchell[1]

Abstract.--Four excellent papers were presented. Three of these dealt with innovative uses of the FORPLAN analysis system. These illustrated the flexibility of this analysis system and the difference between FORPLAN as an analysis system, and the general perception of FORPLAN as a model. One paper illustrated many wide-spread misunderstandings of the FORPLAN analysis system. Five major implications regarding FORPLAN and its use outside the Forest Service are drawn from these presentations.

I want to begin by congratulating the authors of the four papers for this session. Their papers were excellent and raise several interesting points and suggest possibilities for expanded use and support of FORPLAN in the future.

The first conclusion that can be drawn from these papers is that FORPLAN is not well understood outside the Forest Service. This is best illustrated by the paper by Lois Dellert. She discusses reasons that FORPLAN was not selected as an analysis tool for dealing with problems within British Columbia. These reasons include the differences in context between problems faced by the U.S. Forest Service versus those faced by British Columbia; the type of modeling that best fits the British Columbia situation; and the resources necessary to implement FORPLAN.

Of these three, the most valid is the third reason. FORPLAN is now fully supported on a Univac[2] computer system, while most outside the Forest Service use IBM[2] computer systems. The export of FORPLAN from Univac to an IBM system is no trivial matter and requires much technical computer support and knowledge. This is perhaps the biggest impediment to widespread use of FORPLAN and is discussed in great detail in the other three papers.

The other three papers appear to dispute the first two reasons Ms. Dellert poses for not using FORPLAN. These other papers present many varied uses for the FORPLAN analysis system. This includes research and educational purposes, applications for assisting state-wide planning, and applications for investigating alternative investment strategies for management of forested areas. Clearly, the FORPLAN analysis system can be used to build analysis models tailored to the specifics of a particular problem. Further, the size and complexity of the resulting models can be tailored to the analysis questions being addressed and the resources available for analysis. This is supported by experience within the Forest Service where some very simple models have been constructed for a Forest that cost $5.00 to $10.00 for a complete run to very complex models requiring more than $1,000.00 for a complete run of an alternative. Of the four papers presented, this is best illustrated in the paper by Mott and Peters in their discussions of tailoring a FORPLAN model to an industrial problem.

All four papers address two other problems associated with applications of the FORPLAN analysis system outside the Forest Service. The first of these is training and documentation. Documentation in terms of users guides for either version of FORPLAN are difficult to understand to the uninitiated. This problem is overcome within the Forest Service to some extent through internal training sessions and "hot-line" support provided by the Land Management Planning Unit at the Fort Collins Computer Center. For those outside the Forest Service, there have been few training sessions provided and access to the "hot-line" can be difficult to acquire.

A second, related problem, is that even with some basic FORPLAN training and a modest understanding of the analysis system, there are often specific problems that arise. These problems relate to questions of how to tailor a model to address a particular situation. This was discussed as "high level consultation" in the paper by Davis. Again, within the Forest Service, such consultation is often provided by analysts at Regional Offices and by the Land Management Planning Unit at Fort Collins. These resources are not routinely available to those outside the Forest Service. This means that some one outside the Forest Service may have to flounder through a time consuming trial and error approach to discover how to address a particular problem. This is often beyond the resources of such users, however.

A reading of the papers leads to five conclusions that appear valid in light of experience gained by many users over the past 6 years:

1. FORPLAN, as an analysis system, can be a very useful tool for building an analysis model to address a wide variety of problems. Such models can be tailored to the specifics of a situation and the resources at hand. Often, use of FORPLAN

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[2] The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

is a superior way to approach resolution of analysis problems.

2. Export of the FORPLAN analysis system to other computer systems presents a major barrier to its use. Those that have exported it have commented on the difficulty and complexity of this task.

3. Another major barrier to applications outside the Forest Service is the quality of documentation in terms of users guides and the lack of available training sessions.

4. If problems of exporting the system, documentation and training were overcome, there still appears to be a need for "high level consultation" where those most experienced with FORPLAN can help users resolve specific problems.

5. To those who have never built a FORPLAN model or used it for analysis, FORPLAN appears to be very complex, unwieldy and not capable of dealing with problems outside of National Forest Planning. For those who have experience with FORPLAN, the perception is just the opposite with almost unlimited list of possible applications.

Implications that can be drawn from these conclusions begin with an assertion that through the combined efforts of K. Norman Johnson and the Forest Service, a very powerful analysis system has been developed. It could be of benefit to States, University programs of teaching and research, consultants, and private companies. Before the full benefits of this system can be realized, though, the problems identified in the five conclusions must be overcome. These are not insurmountable problems. The question at this point, though, is: Is there anyone with the knowledge, authority and resources to overcome these problems on a wide enough scale to be of general benefit? The FORPLAN users network suggested by Larry Davis may be a move toward that end but does not appear to be a complete answer. Another suggestion is that this could be the responsibility of the Forest Service, perhaps through a restructuring and enlargement of the charter for the Land Management Planning Unit at Fort Collins. Implications and the propriety of such a move would have to be carefully investigated before such a move could be initiated.

In summary, there appears a great potential for the benefits that can be derived from application of FORPLAN to applications beyond National Forest Planning as illustrated in the papers presented in this session. There are at least five impediments to this. Solutions of these are possible, but probably long term. Thus, applications outside the Forest Service will probably remain with those who have the energy and resources to overcome these impediments on their own.

Session III:

Evaluation of FORPLAN and Implications for Management and Research.

FORPLAN: An Economic Perspective

John H. Beuter and David C. Iverson[1]

Abstract.--FORPLAN is adequate for considering economic aspects of forest planning, but its application can be improved. Rather than viewing FORPLAN as a comprehensive optimizing tool, it would be better to consider it a tool kit capable of analyzing a wide range of problems in output scheduling, land and resource allocation, transportation and project planning. It might best used as the means for determining the best feasible forest management activities in a process that builds comprehensive forest plans from the bottom up. Interaction between analysts and forest-managers is necessary if plans are to be useful.

THE CONTEXT FOR FORPLAN

What Is FORPLAN?

FORPLAN is a linear programming model designed expressly for comprehensive forest planning in which interactions among forest activities and resources are to be considered. It is driven by a primary objective to maximize or minimize something, e.g. maximize present net value. The primary objective is constrained by resources available now and over time, and sub-objectives related to the use and production of forest resources, the protection of environmental values, and the preservation of long-term forest productivity. FORPLAN mathematically determines the most efficient way to achieve the specified objectives, given the resources and production possibilities available.

This paper focuses on the use of FORPLAN for national forest planning. Theoretically, FORPLAN is a means to an end, the end being an efficient allocation of resources to maximize net public benefit. The theoretical model envisioned by the laws and regulations governing national forest planning is a general equilibrium model that includes consideration of all relevant linkages, costs and values. There is a considerable gap between theory and reality because of limitations of the model, data, people who bring together information and use the model, and laws, regulations and policies that influence how the model is employed. These limitations for the two versions of FORPLAN and similar models are well documented elsewhere (e.g. Iverson and Alston 1986, Alston and Iverson 1987, Behan 1981, Chappelle 1977, Chappelle et al. 1976).

Optimal real-life solutions are not likely to be found solely by using FORPLAN. This is upsetting to technocrats who believe that mathematical solutions within an optimizing framework ought to be accepted at face value. Nobel laureate Herbert Simon calls this "mathematician's aphasia" whereby "the victim abstracts the original problem until the mathematical or computational intractabilities have been removed (and all semblance of reality is lost), solves the new simplified problem and then pretends that this was the problem he wanted to solve all along. He hopes the manager will be so dazzled by the beauty of the mathematical formulation that he will not remember that his practical operating problem has not been handled." (Simon 1977).

We wouldn't want to leave the impression that the creators and users of FORPLAN have deceived anyone about the role of FORPLAN in the planning process. Some of these people are among the most candid critics of the model and its use. If anything, it is the managers and policymakers who foster the image of FORPLAN as the great optimizer, and with good reason. Law and regulation require interdisciplinary analysis and the evaluation of alternatives as part of the planning process. The people in charge need some way to document that this has been accomplished.

The servicing of FORPLAN and the resulting piles of computer output provide documentation that interdisciplinary analysis has occurred. The solutions for several scenarios, each favoring a different resource or management emphasis, offer a feel for the range of possibilities. Each solution is optimal (efficient) given the structure of the problem.

The chance that any of the solutions is a real-life optimization of public net benefits is remote. Even if one were, we'd have no way of recognizing it, nor of making sure it was implemented as envisioned. There is no way to guarantee it would survive the vagaries of public debate and bureaucratic decisionmaking to be selected as the management plan. If selected, there is no way to guarantee it would be properly budgeted or implemented on the ground.

It is necessary to put FORPLAN itself into perspective before we can give an economic perspective of it. FORPLAN is not the global optimizer of human and environmental welfare that some believe it is or ought to be. It is an abstraction of reality. It is a tool for strategic planning that helps us gather our thoughts and explore tentative paths toward the achievement of our objectives. Rather than a means to an end, it is a means to a beginning, the beginning of the process of public involvement in the development of strategic plans for our national forests.

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Who Needs FORPLAN?

FORPLAN is needed to meet the requirements that arose from the passage of the National Environmental Policy Act of 1969 (NEPA) (Act of January 1970; P.L. 91-190, 83 Stat. 852), the Forest and Rangeland Renewable Resources Planning Act (RPA) (Act of August 17, 1974; P.L. 93-878, 88 Stat. 476) and the National Forest Management Act of 1976 (NFMA) (Act of October 22, 1976; P.L. 94-588, 90 Stat. 2949). Professor Wilkinson covers statutory requirements in these proceedings. Without benefit of his insight as this is written, it seems that some sort of model is necessary to evaluate alternative strategies for the use, management and conservation of the national forests, whether it be FORPLAN or something else.

The need for FORPLAN rests on the presumption that it is the best available way to accomplish or at least improve some aspects of the planning process, education and communication or decisionmaking.

The Planning Process

Among other things, the planning process is required to include "a systematic, interdisciplinary approach to ensure coordination and integration of planning activities for multiple-use management." (36 CFR 219.1(b)(10)). It must include an analysis of the management situation, collection and display of data, formulation and evaluation of a reasonable range of alternatives, and documentation of the process for use in public participation and decisionmaking (36 CFR 219.5-219.7).

FORPLAN serves several purposes in the planning process. It provides some degree of standardization among national forests in the formulation of the planning problem and in the preparation, use and presentation of data and assumptions. It provides a focus for the process and a means for evaluating and comparing the long-term effects of alternative plans on resource availability and values. The advantage of FORPLAN over other models that might be used is that it was designed and has evolved explicitly to meet the technical requirements for national forest planning specified by law and regulation. It was also designed with sensitivity to the form in which resource inventory data is available on the national forests. It is unique in its capability to change management prescriptions for a given area over time, to account for contiguous land use zones within the broader planning unit, and the uniqueness of a mix of resource values for a land use zone (Iverson and Alston 1986).

Education and Communication

Perhaps its role in education and communication is the most important for FORPLAN. As a focus for planning, it is also a focus for talking about and understanding the planning process. That this symposium features FORPLAN and not the planning process is testimony to that.

A given plan for a national forest might have been selected by any number of means, including working it out on the back of an envelope. The problem faced by a national forest manager is to convince people with differing backgrounds, from professional foresters to housewives, that the plan has taken all concerns into account and is the best of all plans given the circumstances. In the past, the forestry profession was able to assert its special qualifications (expertness) in forest management and could make decisions without much explanation about the process. It was sufficient to assure the public about sustained timber yields and regulated forests while giving lip service to multiple use. Just leave the details to the professionals and trust them.

FORPLAN provides a means of opening the process and revealing the paths by which a solution is obtained. It provides a common language and structure for communication within a planning team comprised of experts in diverse aspects of forest use, management and protection. It provides a means for the team to assure the decisionmaker and the public that a thorough analysis was done: to show them the structure of the analysis, the data and assumptions, the evaluation of alternatives, and even to reveal weaknesses and omissions. Used to display a range of alternatives, FORPLAN functions as a simulator in an optimization framework. It protracts the knowledge and thoughts of the planning team in terms of proposed actions and their consequences.

A FORPLAN analysis provides a base of knowledge and a focus for negotiation. There always will be much to be learned from it and the debate it fosters about forest resource interactions, forest practices and consequences, costs and values. The highly visible structure of the analysis provides a means to pinpoint areas of disagreement and a means for testing suggested ways to improve.

It remains to be seen whether we're any better off because of improved education and communication among interest groups, but FORPLAN should help increase respect for the expertness of the planners and managers of the national forests. As Simon (1977) puts it: "We choose among experts by forcing the experts to disclose how they reached their conclusions, what reasoning they employed, what evidence they relied upon. Having made this disclosure, they have exposed their assumptions and reasoning to the scrutiny and challenge of other experts....we [all us experts, including the man on the street] are quite prepared to examine and judge for ourselves those tenuous paths of common-sense dialectic that commonly connect a specialized fact with a general consequence in the real world. We can do this if the paths are revealed."

Decisionmaking

Will FORPLAN lead to better decisions? Again, there is no way of knowing. The decisions made with FORPLAN might be the same ones made without it. The reasons to expect FORPLAN to lead to better decisions are imbedded in the likelihood that it has helped improve the planning process, education and communication. Informed decisions are likely to be better than ones made in ignorance of data, assumptions, processes and consequences. The theories of both our democratic form of government and our free-market economy are founded on an ideal of "perfect knowledge" or at least open access to all the information available.

FORPLAN may not yield solutions that are optimum in the real world--it doesn't have to. It just has to contribute effectively to decisions that are acceptable across the interested political spectrum. It must be perceived that these decisions provide at least as much net social benefit as ones that could have resulted from other analyses. What the public lacks in understanding has to be covered by their trust in the planners and the process. Economic efficiency is an important criterion for judging both.

ECONOMIC EXPECTATIONS FOR FORPLAN

To an economist, the ideal forest planning model should be capable of maximizing net social welfare or net public benefits (Iverson 1985, Bowes and Krutilla 1986). The model should include production possibilities for all goods and services from the forest (the production surface), an objective function hyperplane that reflects expected net prices or values of goods and services, some means for handling desires that aren't accounted for in market prices or imputed values, and the capability of finding the point of tangency between the objective hyperplane and the production surface that maximizes net public benefit. That essentially describes FORPLAN, and why shouldn't it? FORPLAN was designed with the ideal in mind, to approach it, if not reach it. This leads to certain economic expectations for forest plans derived from FORPLAN analyses.

Social Welfare

The concept of maximizing net public benefits (NPB) doesn't differ much from the direction given to Gifford Pinchot in 1905 by Secretary of Agriculture James Wilson that "...where conflicting interests must be reconciled, the questions will always be decided from the standpoint of the greatest good for the greatest number in the long run." (USDA Forest Service 1983). By focusing on the greatest good alone ("net" good, that is), the maximization of NPB gets away from the impossible task of reconciling "greatest good" and "greatest number." The economist's ideal model takes care of the "long run" by discounting. In practice, law and regulation override simple discounting by imposing constraints such as those to insure reforestation and sustained timber yields.

Just as FORPLAN is only an approximation of the ideal model, its solutions are at best only an approximation of maximum social welfare. Social welfare is represented to the extent that it is possible to reflect in FORPLAN objectives and constraints the needs and wants of society, now and in the future, and all the interrelationships among production possibilities and competing demands for the goods and services from the forest. The use of harvest flow constraints to meet the needs of local industry and foster community stability is an example of moving FORPLAN solutions toward what some would consider greater social welfare as defined by Forest Service policy. If this isn't truly a move in that direction, you can't blame FORPLAN--it is only following orders.

Supply and Demand

An ideal model would distill all that is known about markets and seek an efficient allocation of factors of production to meet demands for goods and services from the forest. Setting aside the more ethereal aspects of what forests contribute to social welfare, the forest can be viewed as a factory capable of producing a wide range of marketable goods and services, jointly (multiple use) and separately (dominant use). For a fixed land base and without consideration of a labor constraint, there are three classes of production factors to consider: inherent (e.g. soil), accumulated (e.g. growing stock), and, recruited (e.g. marginal investments in such as roads and stocking control). The expectation is that resources would be allocated such that the marginal cost of the the last unit of production would equal the marginal revenue to be received. The expectation value of the soil will be maximized. Appreciating assets, such as timber, would be retained as long as their marginal value increment exceeds their marginal opportunity costs associated with other (non-timber) uses of the land and the net cash revenue from harvesting the timber. Marginal forestry investments should yield a satisfactory rate of return.

Joint production of resources (e.g. timber and wildlife or timber and water) would be accounted for in terms of the joint costs of production and relative resource values. For example, it may be economically efficient to cut rapidly growing timber in favor of increasing elk herds or water flows, even if the revenue from the timber harvest doesn't cover the cost of selling and removing it. That is, a below-cost timber sale may be the least-cost way of meeting a wildlife or water objective (demand).

The ideal model would easily make such trade-offs in terms of relative values and costs over time. In real life, the trade-offs are more likely to be imposed by prior analysis such as the exogenous determination of economic suitability for timberland, or set-asides for spotted owls based on biological rather than economic criteria, or by constraints in the FORPLAN analysis that set prescribed production levels for the various resources in each time period. There is little assurance that economic expectations can be met. Again, the model does what it is told to do.

Forest Operations

Some people expect the results of the planning process to translate to economically efficient practices on the ground. That is, the solutions should lead to the production of a desired mix of goods and services at minimum cost. Or, they should provide the maximum output of desired goods and services for a given budget.

It seems remote that even the ideal forest-wide planning model could have much relevance at the project level if it is employed from the top down and constrained by exogenously determined demands and requirements. Even if the production possibilities in the model accurately reflect local marginal costs (which they don't in real life), local unit managers could be forced into money-losing (negative cash flow) operations by production quotas imposed by the plan. For example, the plan might set aside high productivity timberland for aesthetics and force local timber operations onto lower productivity land to meet timber production quotas. Or, the amount of the timber quota itself might force local timber production up to where marginal cost exceeds market price. This is not necessarily bad in the broader context of forest planning, but can result in criticism of apparently uneconomic forestry practices, as in some below-cost timber sales.

Forest Planning

It is common to hear how expensive the national forest planning process is and how much it costs to make FORPLAN runs. The planning process is not unlike a military operation where effectiveness has considerably more weight than efficiency. Regardless of what it costs to run the model, the same questions need to be answered. The same information has to be gathered. The interdisciplinary team has to be paid.

The planning process is expensive and cumbersome, FORPLAN runs are expensive and, probably too many are being made, some of which are overly complicated. So what?

It is hard to think of projects outside of the Defense Department or NASA that have involved the complexity of post-RPA Act national forest planning. This is the first pass at it. The development of FORPLAN and the planning process is simultaneously research and operations. It would be surprising if it weren't expensive. Having come this far in the development of FORPLAN and the planning process, the priority for now is effectiveness. Efficiency will have a higher priority later.

DISECONOMIES AND OTHER PROBLEMS WITH FORPLAN, THE PLANNING PROCESS, OR BOTH

It is hard at times to figure out whether the planning process drives FORPLAN, or FORPLAN drives the planning process. In the last section we looked at economic expectations people might have for FORPLAN. They could just as well have been expectations for the planning process.

"Policy is enunciated in rhetoric; it is realized in action." Paraphrasing this opening sentence in Kaufman's (1967) classic study of the administration of the Forest Service, we might say "Forest plans are enunciated in FORPLAN; they are realized in action." Considering all the attention being paid to FORPLAN in recent publications and this symposium, one might wonder if we haven't lost track of what we are trying to accomplish. The tone set by Kaufman may be the same one we ought to have for our evaluation of FORPLAN and the planning process: In public forestry, nothing much matters if we are screwing up on the ground and in the halls of Congress.

It is easy for quantitative economists to get caught up in the eloquence of mathematical modeling and, as noted in the quote from Simon, lose track of reality. Consider the evolution of FORPLAN (Iverson and Alston 1986)--from Timber RAM to MUSYC to FORPLAN, Version 1 to FORPLAN, Version 2. Each innovation aimed at making the model more realistic, more suited to the particular aspects of forest planning and management, more sensitive to limitations in the availability and form of data, and the desire for output. As it evolved in search of the elusive optimum optimorum, the model improved for some purposes while retaining its capability to do what was useful in the past, i.e. it got more complicated. In discussing innovations in Version 2 FORPLAN, Iverson and Alston (1986) quote FORPLAN's principal author, K. Norman Johnson, as saying that the new forest activity scheduling choices are "time-consuming to construct and require considerable imagination." Referring to the same innovations, environmental writer Randal O'Toole is quoted as saying they will lead to complication at the level of "total unintelligibility."

From the perspective of the model-builder (Johnson), the model is improving, but getting harder to use. To a critic and public observer of forest planning (O'Toole), the added complication will just make it harder for him and his constituents to understand what is going on. We are faced with the prospect that we have a better model that is making life harder for the forest planners and the public, and it's not yet clear it is leading to better forest plans. How does this make us any better off?

Again, the problem is with expectations: Expectations for optimization, for social and economic efficiency, at all levels, for everyone; expectations that everything will fit together in a logical way, and that forest plans will translate easily into budget requests and on-the-ground implementation.

Links Between Forest Planning, the RPA Program, and the Budget

Recently, the Forest Service presented its latest 5-year RPA program to the Congress. It called for increasing the annual timber harvest from the national forests from 11.4 billion board feet now to between 15.6 to 20 billion board feet over the next 45 years. "I don't know what the hell we're doing, if you want to know the truth," said Representative Leon Panetta of California as he questioned how the RPA program meshed with 125 separate forest plans (Portland Oregonian, 9/24/86). His reaction was not surprising, given that the plans from some of the largest timber-producing forests in the nation have yet to be issued, and the forecast is that allowable cuts for some of those forests will decline significantly. How then can the RPA program project a significant increase in national forest harvest?

The RPA program is the basis for requests to Congress for budgets to carry out the management plans on the national forests. It is logical that there should be some link between the forest plans, the RPA program and budgets. But there isn't--at least not any direct link that is apparent now.

The problem may be timing. The Forest Service is required to prepare a program each 5 years to help the Congress in budgeting. The 1985 RPA program was presented almost two years late, perhaps because it was awaiting completion of forest plans that themselves are long overdue. Presumably, the timing can be worked out over time; but there are other reasons to suspect that links between planning and the budget will not be easily achieved.

The Congressional budgeting process is functional in nature, focusing on about 90 line items such as timber, recreation, wildlife, range, etc. Planning involves coordination among interdependent resources such as water and timber, recreation and grazing, or other combinations involving a multitude of resource interactions. There is no easy way to translate costs associated with an integrated resource plan into functional budget categories.

At the other end of the spectrum, forest plans are developed without budget constraints so the "optimality" achieved assumes the availability of funds needed to implement the plan, and in whatever functional areas they are needed. Furthermore, it is likely that forest plans do not reflect the true cost of the activities they portray. The costs used in the plans are usually based on broad averages and don't reflect site-specific circumstances under which the plans eventually will have to be implemented. The costs are based on past experience that includes costs hidden in timber sale contracts (trading timber for services) that are not reflected in current Forest Service budgets (Beuter 1985). They also may represent local conditions and bidding practices that reflect a world that no longer exists or is less likely to exist in the future. The point is that the plans are not likely related to prevailing budget levels, and that budgets developed from the forest plans may not represent the amounts needed to implement the plans.

Then there is the matter of exogenously developed quotas that may be imposed upon forests in the planning process. What if Congress were to buy the proposed 1985 RPA program and fund an annual timber sale program of, say, 17 billion board feet, while the current forest plans reflect optimality at, say, 11 billion board feet? In effect, this would be a clash of optimalities. If we believe the RPA program analysis, public net benefits will be maximized by higher harvests from the national forests to meet expected increases in the demand for timber (presumably by holding down consumer prices). It is presumed to be technically possible to achieve the increases without compromising environmental and non-timber resource values. But the lower harvest levels prescribed by the forest plans are largely because of the need to protect environmental and non-timber resource values.

There appears to be incompatibility between the RPA program analysis and the forest planning analyses, either in timber production possibilities or constraints related to other resources and environmental values. Congressman Weaver may be correct when he asserts that increased timber harvesting would come at the expense of wilderness and wildlife values (Portland Oregonian, 9/24/86).

Links Between Forest Plans and Forest Operations

FORPLAN, Version 2 provides the capability to consider site-specific management on the national forests. It is possible to consider unique resource interactions and values within specified zones, and have timber harvest and other resource outputs allocated specifically to that zone as a result of optimizing the objective function. Doing so provides useful information about the priorities for specific areas, e.g. watersheds, in the achievement of an optimum plan for the forest. Unfortunately, what appears optimum for the forest may not be optimum for a watershed.

It is in this consideration that one may get queasy about the use of linear programming for large-scale forest planning. The problems involved in the classic uses of large-scale LP models in the chemical, petroleum, railroad and communication industries, the Department of Defense, NASA, and even agriculture just aren't the same as the problems involved in large-scale forest management. It isn't just a matter of scheduling machines, transportation routes, boxcar loading, cracking plant capacity, or how many acres to devote to wheat, corn and milo.

Sub-areas of a forest are dynamic ecosystems, almost any of which can be considered unique in some way. Because of some characteristics, they are not interchangeable. For example, timber in one drainage is not the same as timber in another drainage. Although stands may have similar structure and characteristics, their unique location and relationship to surrounding plant, animal and human communities may give them special values or costs.

None of this is news; and we don't mean to imply that there is insensitivity to it in national forest planning. Version 2 FORPLAN was developed to help account for site uniqueness. The problem arises because the major focus of forest planning is the annual allowable timber sale quantity (allowable cut). Timber harvesting and related road construction and development drastically change things on the forest. The allowable cut is a highly visible and politically volatile standard against which to measure forest performance. Once announced, there is much pressure to get out the cut and maintain it.

Linear programming is very well suited to timber harvest scheduling, *per se*. But, despite the existence of allocation choices and zones, the FORPLAN allowable cut is only a tentative one based on the planning assumptions about economic and environmental suitability of land for timber production, roading costs, logging costs, timber quality, and revenues. In the past, precise knowledge about stand or area operability was not a major concern because there were many options for where the allowable cut might come from within a ten year period. If a proposed sale area was found to be a problem, that area could be set aside and another selected. On the western national forests, a considerable error associated with the tentative allowable cut might not even be noticed because it could be absorbed into the cushion provided by the backlog of overmature timber.

As the backlog of old-growth diminishes and concerns increase about the environmental and economic circumstances of individual timber sales, the cushion for absorbing errors is disappearing. The objectives and consequences of harvesting must be better thought out today than in the good old days when it was sufficient to justify the timber sales program only based on converting overmature, slow-growing stands to young, thrifty stands. Not only is there concern about environmental effects, but increasing scrutiny of the economic effects. In the past, the planned allowable cut could be (and was) viewed as God-given and carried out without further question. From now on, planned allowable cuts will more likely be viewed as tentative, pending site-specific analysis and verification.

The link between operational feasibility and forest plans is tenuous despite the improvements in Version 2. The allowable cut allocations of the forest plan might be changed considerably by site-specific (project) analysis, sometimes increased, sometimes decreased, depending on local concerns. Ryberg and Gilbert (1986) have shown how site-specific (zone) FORPLAN optimization could increase the allowable cut and present net value for the zone (from negative to positive) compared with the allocation from the forest-wide plan, while decreasing anticipated road construction and meeting environmental constraints. One has to wonder why the planning analysis isn't built from the ground up in the first place, starting where the plan is to be realized--where the action is.

The Link Between Forest Planning and the Outside World

We have discussed planning links upward to the budgeting process and downward to specific sites on the forest. The consideration here is the link outward to the rest of the world.

The incongruity between the RPA program and forest plans is at least matched by the incongruity between the forest plans and what is going on outside the national forests. Exception for harvest flow constraints aimed at controlling prices for wood products or the flow of timber to dependent communities, there has been little effort to develop national forest plans with sensitivity for the management of surrounding lands in other public and private ownership, nor the social and economic impacts that might derive from the the plans. Such considerations may be trivial for many of the 125 or so national forest planning units, but they are an important consideration for the heavily timbered forests of the Pacific Northwest. They also may be important where commercial development for recreation, water, livestock, and minerals are possibilities. Again, problems arise because of the expectations for optimal solutions. How can we possibly be optimizing net public benefit if planning for the national forests is done in a vacuum?

That isn't to say that the Forest Service is insensitive to this issue. Broad-scale economic impacts are considered in the development of the RPA program. With consideration for local economies, departures from non-declining even flow have been included among planning alternatives on some national forests to at least test for their possibility and show their effect on other national forest resources. Some forests are responding to public concerns about the effects of planning alternatives on local economies.

But there is no report of forest plans being developed by including in the FORPLAN analysis the situation and production possibilities for timberland outside the national forests. Because of this, Oregon is preparing to respond to the upcoming national forest plans with its own analysis of more comprehensive production possibilities including all timberland ownerships (Johnson and Greber 1986). This study will show the possibilities for modulating national forest timber harvest schedules while preserving at least the same concern for environmental and non-timber resources as included in the national forest plans. The objective is to find how Oregon might maximize its net public benefit form all the timberland in the state.

THE ECONOMIC ADEQUACY OF FORPLAN

FORPLAN provides a means to find efficient solutions to well-defined forest resource allocation problems. Whether the solutions are economically adequate depends on the structure of the problem FORPLAN is asked to solve. Some problems may lack economic considerations, e.g. timber volume maximization problems constrained only by physical and biological relationships. Other problems may appear to focus on economics, e.g. maximize present net worth, but because of non-economic constraint the solutions have little to do with economic efficiency. It is possible to set up analyses aimed at economic efficiency, e.g. ones that maximize present net worth or internal rate of return with a model structure that permits the selection of activities at the margin of economic efficiency, subject to meeting minimal legal and institutional constraints.

The economic adequacy of FORPLAN may have more to do with how it is used compared with expectations about economic efficiency than it does with the model itself. Exogenously determined constraints can cause the exclusion from the plan of economically efficient production possibilities, or the inclusion of uneconomic ones. The latter is what happens when a forest plan includes below-cost timber sales and uneconomic forestry investments. The Forest Service defends these apparently uneconomic activities in terms of indirect benefits such as vegetation management for wildlife habitat, aesthetics, forest protection, recreational use of roads, forest development and community stability (USDA Forest Service 1984).

Unfortunately, these benefits are hard to pin down. It is not usually evident that investments with negative cash flows, such as below-cost timber sales and advance roading, are the least-cost way of achieving these indirect benefits.

In remanding the forest plan for the San Juan National Forest, the Secretary of Agriculture asked the Forest Service:

> "Is the timber program as currently proposed actually the most cost effective way to achieve the non-timber multiple use objectives of the plan?...To what extent can the timber program costs be cut and/or revenues be enhanced while still providing an appropriate level of non-timber multiple use objectives?" (July 31, 1985).

To answer these questions, the forest must look at alternative production possibilities for achieving forest objectives, presumably ones that were not included in the original FORPLAN analysis. The implications are that there might be cheaper ways to achieve non-timber resource objectives than to make below-cost timber sales. At least the plan should be convincing in the need for such sales to achieve non-timber objectives.

Bowes and Krutilla (1986) show how FORPLAN can be used to analyze the separable costs of joint forest outputs such as timber and water. To do so, the analyst must know the least cost way of achieving the separate resource objectives--exactly the information the Secretary is asking about for the San Juan National Forest. Through successive FORPLAN analyses eliminating one resource at a time, it is possible to determine the incremental (separable) cost associated with the planned output level for each resource. Such an analysis may or may not prove the assertion that a below-cost timber sale program is justified by non-timber benefits; but it would have much more credibility than the current plans in which the public is expected to take it for granted that money-losing timber sales increase net public benefits. As an appellant of a forest plan recently put it: "Why jeopardize fish habitat and risk wildlife loss with timber sales that lose money for the government?" With all the time and effort that has gone into the plans, it is hoped the Forest Service can provide a good answer.

The economic relevance of FORPLAN analyses also is affected by specific assumptions about prices, costs, values, and production possibilities. O'Toole (1986) argues that many forest plans are not on the true production possibility frontier because of the use of high timber price trends that delay harvest in the early periods to take advantage of higher prices in later periods. None of this is the fault of FORPLAN.

In December 1979 the Forest Service adopted FORPLAN as the required analysis tool for forest planning (Iverson and Alston 1986). With benefit of hindsight, this decision may have had the good intentions of settling on a consistent way among forests to maximize public net benefits, but the FORPLAN adopted (Version 1) was little more than a sophisticated means for timber harvest scheduling that "was bound to fail as a universally applicable model because it simply was incapable of...[providing] meaningful answers [about] what would happen and where it would occur as a result of the forest plan in the next 10 years." (Iverson and Alston 1986, quoting K. Norman Johnson).

Given the state of knowledge at the time FORPLAN was adopted, it is not surprising that many people had inflated expectations for what it would do. However, even with the improvements since then, it is still not the universal and complete planning model that some believe we need. It never will be.

It is debatable whether it even should be used for large-scale, forest-level planning, at least not with the level of sophistication now used. Version 2 may be best suited to site-specific project analysis involving coordination between forest development and resource use and production, and timing choices.

We should not overlook the realities that govern what will happen on the national forests. Allocations for wilderness, the preservation of old-growth timber, riparian zones, and other sensitive resource issues are likely to be made outside the forest planning process, and enter into the process as constraints or reductions in land and resource availability.

Budgets for national forest management will be carried along by momentum from past political acceptability, including some amount off-budget discretion associated with timber sales. The timber sale program will always dominate the budget justification because of the size of its budget, its importance for local economies, the amount of Forest Service employment and activity associated with it, and the perception that it makes money for the U.S. Treasury. For heavily timbered forests having prospects for growing timber economically, there will be pressure to maximize the allowable cut, subject to meeting the minimum requirements for environmental protection and non-timber resources.

For forests that have established timber programs, but on which timber production is a questionable economic venture, the pressure will continue to justify the timber program in terms of what it contributes to the production of other resources, the protection of other values or community stability.

What is the role of FORPLAN in this? It is a valid means to evaluate alternatives at the project level and above, and to determine allowable cuts while accounting for environmental concerns and other constraints. It provides a structure that is useful for communication and education, and as a means to test "what if" questions.

There is little doubt that the role of FORPLAN in the planning process needs to be refined to increase both effectiveness and efficiency (see Barber 1986). It may be much better suited to site-specific project analysis, such as for a watershed, than it is to large-scale, forest-level analysis. It may be better to employ FORPLAN at the project level and build the forest plans up from site-specific analyses, rather than trying to develop forest-wide optima that may translate into site-specific problems.

FORPLAN is a significant accomplishment as a tool for planning forest management activities. It is serving an important role as the focus for thinking about comprehensive, interdisciplinary planning, and for education and communication about forest plans. It probably has done more for educating people, foresters, and others, about the complexity of the of multiple use forest management planning than it is done for solving the problem of getting out the plans.

Yet, what credibility would the plans have without FORPLAN analyses?

If not FORPLAN, what?

EPILOGUE

A forest planning system such as FORPLAN can be evaluated in at least two ways. An evaluation of interest mainly to model builders and operations research theorists focuses on a generic matrix generation package that can be linked to a solution algorithm designed to solve a specific mathematical programming problem.

A second type of evaluation focuses on the results from the application of the system and is more of interest to forest managers, the Congress, and groups with special interests in forest planning. The following comments address both types of evaluation, though it is too early to thoroughly evaluate the the results of applying FORPLAN to forest planning.

The development of FORPLAN reflects a "maximizing" strategy rather than an "optimizing" one. FORPLAN is more a tool kit than a tool. Much like a PAC MAN, FORPLAN has gobbled up several systems designed to solve specific problems in output scheduling, land and resource allocation, transportation planning project planning, and combinations thereof. Unlike PAC MAN, however, FORPLAN has retained intact the systems it gobbled up, thereby allowing users to analyze problems from varied perspectives.

The multiple model framework of Version 2 contains elements of Timber RAM, ADVENT, IRPM, RAA and others. From a researcher's standpoint, it provides a means to evaluate various paths of analysis for a variety of natural resource management problems. Whether it's of use from a manager's standpoint depends on whether the results have any practical application. Can they be implemented on the ground? Can they be used to justify budget requests?

Successful use of FORPLAN to solve planning problems and meet the needs of practitioners in forest management requires investment in several key areas. System software support, training of analysts, and consultation with users are all needed to assure thoughtful and efficient use of the system. Management analysts must be carefully selected for their ability to shift between the complexity of FORPLAN and the technical, social and political complexities of day-to-day forest management. FORPLAN can sort out mathematically infeasible solutions, but is incapable of recognizing ones that aren't feasible in real life. It takes interaction with real forest managers with names such as MARVIN to avoid those kinds of infeasibility.

Stressing the human aspects of planning should not be construed as rejection of any analytical system, whether large mathematical model or otherwise. The point is: the system is not the solution; people are. Long-range planning is nothing more or less than risk-taking decisionmaking. If we don't give any thought to where we are going, any road will get us there--and without planning, there's a good chance we won't like where we've arrived.

The role of planning analysts is to aid the thought process. There must be interaction between analysts and managers. True optimization will occur if there is agreement on the problems to be analyzed and it turns out the results of the planning process are meaningful and useful.

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Discussion of FORPLAN: An Economic Perspective

John Hof[1]

Abstract.--Linear programming (FORPLAN) is evaluated as an applied economic efficiency tool: activity analysis is contrasted with a production function, spatial considerations are discussed, the need for an acre-by-acre solution is evaluated, and the problem of response discontinuities are analyzed. The linkage between FORPLAN and regional and national planning is also discussed.

The paper by Beuter and Iverson (1987) provides a good overview of the economic content and usefulness of FORPLAN. I will try to expand upon their paper in two broad areas: further evaluation of linear programming as an applied economic efficiency tool, and the linkage between FORPLAN (the forest planning effort) and RPA (higher level planning). The selection of these two areas and my remarks about them reflects my own experience, interests, and on-going personal research topics.

Linear Programming as an Economic Model

FORPLAN is a matrix generator and a report writer linked to a linear programming solution package. A diligent, creative analyst can do almost anything with any version of FORPLAN that can be done with a linear program. An evaluation of FORPLAN is, therefore, an evaluation of linear programming--or at least the type of linear program that has been used (with or without FORPLAN) in timber harvest scheduling and forest resource allocation models. Therefore, linear programming (LP) will generally be referred to hereafter, rather than FORPLAN.

Activity Analysis Versus a Production Function.

Economic analysis of a production process, such as that encountered in managing a forest ecosystem, generally starts with a production function. This is a function, not generally observable, that relates inputs (factors of production) to outputs (the things being produced). The production function is defined to show "technically efficient" output levels given the inputs. If only one output is involved, this means that the production function will show the maximum output possible for a set of inputs. If more than one output is involved, the production function will indicate a set of output possibilities such that no more of any one output could possibly be produced without an ancillary reduction of some other output or outputs, given any set of inputs. The use of the production function assumes that the engineering problem of determining physical production technology has been solved and the economic analysis proceeds from there.

As Herfindahl and Kneese (1974) state:

> "...we must now recognize that in something as complicated as many natural resource management systems, the engineer cannot be expected to supply the economic analyst with a production function...Even a simple problem involves a huge number of alternatives...Thus, water resource planning presents a complex and difficult problem of design which in practice does not allow the neat separation of technological and economic factors implied by the production function analysis." pp. 281-282.

Thus, an economist would hope that an LP would be capable of solving the engineering problem of technical efficiency and the economic problem of choosing the input set and the output set that maximizes net benefits.

Because we cannot specify the production function that directly relates inputs and outputs, we have resorted to linear programming which is a type of activity analysis. By this, I mean that in an LP, inputs are clustered into packages or activities, and then the LP attempts to solve the engineering problem of technical efficiency and the economic problem of input and output selection simultaneously. It is remarkable that an LP, at least in principle, could perform such a feat.

However, if an LP is to even come close to emulating a production function, the activities--management prescriptions in FORPLAN jargon--have to include (implicitly) a variety of possible input sets, a variety of possible output sets, and somewhere in all the activities included, the technically efficient means of combining the two. It seems that this is the most fundamental assumption required to claim that an LP is achieving an economically efficient solution--that somewhere in the LP, the "correct" solution is available for the LP to select. In other words, in representing the production system with a collection of activities, the only way that a production function is likely to be emulated is if the activities include every possible combination of inputs that is technically feasible. Given the pragmatic limitations of any planning exercise, it is not clear that any LP represents all the relevant production possibilities. If the LP is designed to reflect only modest changes from current practice, then either we are close to being efficient already (and the planning problem is nearly trivial) or, more likely, the LP will not emulate the production function and will not be capable of approximating economically or even technically efficient solutions.

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Spatial Considerations--The Real Nonlinearity Problem.

The next most fundamental weakness of LP is probably its linearity. This statement should not be misunderstood. LP can be used to piece-wise approximate highly nonlinear relationships between inputs and outputs. For example, if different management prescriptions are included that involve different levels of intensity of some input's utilization, the different A-matrix coefficients under these different management prescriptions can reflect highly nonlinear responses to changing input intensity.

The linearity assumptions of an LP cause some problems, however. By far the most important of these problems is that of accounting for the impact of the spatial configuration of a management action on the outputs of interest. In terms of outputs such as water, wildlife and fish, and aesthetics, it is probably more important how a management action (for example, a timber harvest) is spatially laid out than how many acres are involved. Version 2 FORPLAN has attempted to deal with this problem by making the LP behave more like an integer program and by defining management prescriptions not on a per acre basis but applying to an entire watershed with a spatial configuration defined. This allows the prediction of the resulting outputs to take the given spatial layout into account; but a serious problem remains. Within the practical limits of the LP, only a tiny number of the possible spatial layouts can be considered. Remembering that the LP will only perform well in an economic efficiency context if all technically feasible options are included, this is not a trivial problem. An example might be useful to illustrate the point.

Imagine a rectangular watershed as depicted in figure 1. Assume that because a low level of resolution is required, we segment the watershed into 25 equal sections (fig. 1). Also assume that we only have one management action (e.g., clearcutting) to consider, versus doing nothing. Even in this very simple example, if each of the 25 sections could be clear cut or not, 2 to the 25th power or over 33 million spatial configurations are possible. With more potential management actions or with finer resolution, the number of spatial possibilities approaches google numbers very rapidly. Add the scheduling problem (dynamic considerations) and the problem defies conceptualization.

If, however, management prescriptions were based on a per acre basis, the LP determines at least the number of acres to which each management prescription applies. The problem is, the (nonlinear) response to different sizes and shapes of the management action is lost in a fixed per-acre production coefficient. The magnitude of this problem should not be minimized. The spatial considerations are so important that most of the forest outputs cannot be determined with any reliability at all on a per acre basis. Also, we simply have no means to analyze a reasonable representation of the spatial options that are typically available.

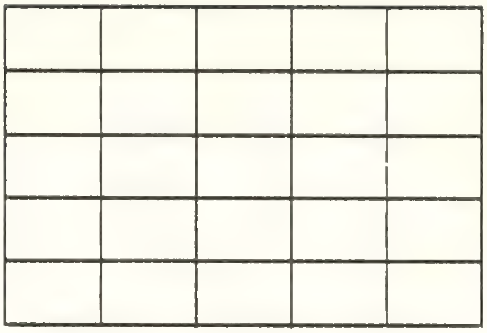

Figure 1. A square analysis area segmented into 25 parts.

The Need for the Acre-by-Acre LP Solution.

The previous two sections should provide a feel for just how ambitious the task is that FORPLAN models have apparently been intended to accomplish. The FORPLAN model is being asked to solve the engineering problem and the economic problem previously defined for a very complicated production system that includes spatial and temporal placement of management actions on an acre-by-acre basis. The futility of accomplishing this task with a high degree of precision appears to be the theme (and it's a good one) of the Beuter and Iverson paper.

I cannot resist going one step further and ask if this is really necessary. Is the purpose of the forest planning analysis (FORPLAN) to provide a management plan, *per se*, or to provide guidelines in the development of a management plan? The answer might be found as the forests move into the implementation phase of the planning process. If the detailed solution of the FORPLAN models is never really used in implementation of the plan, then it could be argued that it was never necessary. Even if the detailed solution of the FORPLAN models is used, it is not clear that enough of the spatial considerations have been accounted for to make the detailed FORPLAN solutions truly useful in implementation. A more stylized approach oriented towards guidelines rather than detailed global optimization might have accomplished as much or more.

It also might be useful to point out that some models encountered in optimal control and dynamic programming approaches yield decision rules rather than numeric optimal solutions to the choice variables. Although they are more qualitative, these decision rules might be more broadly applicable and more in the spirit of a planning analysis than a detailed quantitative optimal solution. I emphasize that I am only intending to raise questions here; this is discussion not proposal.

Discontinuities

My final comments on LP as an economic tool emanate from the very commonly expressed concerns that LP does not seem to be very effective in dealing with phenomena such as fire, insect and disease infestations, or other dramatic ecological changes. I believe that it is not uncommon for this shortcoming to be attributed to the fact that LP does not incorporate stochastic variation in the response variables with great ease. I also have heard it suggested that LP fails because it does not easily incorporate risk averse perspectives or that it does not account for the desirability of flexibility or the undesirability of irreversible decisions.

All these points are well taken; however, all these weaknesses could be remedied and the LP still would not perform well in terms of modeling things such as fire, insect and disease infestation, etc. My reasoning is as follows. An LP is based on a calculus-oriented formulation of the optimization problem at hand, where constraints and objective functions are smooth, many-times differentiable functions. That is, the basic mathematical foundation of an LP includes an assumption that small changes in choice variables will result in small changes in response variables. Likewise, symmetrical reactions to small changes in choice variables are implicitly assumed.

Phenomena such as fire and insect and disease infestation simply don't behave that way. They behave in fits and starts and at times very small changes in choice variables can cause an immense impact on the ecosystem because of such a discontinuity. I would assert that managing these unstable "catastrophes" is generally more important than managing the ecosystem when it is "well-behaved." I would also assert that we are more likely to learn fundamentally new things about the ecosystem by concentrating on the discontinuities than we are from studying the smooth, slow changing behavior that an LP can handle.

Refocusing our analytical energy on the discontinuities should not be taken lightly or undertaken prematurely. It will require moving into an entirely different area of mathematical analysis. A new branch of applied mathematics called "Catastrophe Theory" has developed out of topology and may show promise in this area. Many questions remain unanswered. A very large part of my research focus over the next 5 years is planned to be in this pursuit. Many researchers around the country are working on Catastrophe Theory, and the potential is very exiting. At this point, however, this work still belongs on the desk of the researcher and is not ready for a planning analysis such as that in forest planning.

Linkage Between FORPLAN and RPA

Beuter and Iverson state:

> "It is logical that there should be some link between the forest plans, the RPA program and budgets, but there isn't--at least not any direct link that is apparent at the present time"

I doubt that there will be very much disagreement that this linkage is logical. Also, I believe it is the intent of the agency to accomplish as much of a linkage between forest planning and RPA as is possible in the development of the 1990 Program. Part of the analysis of resource interactions for the 1989 Assessment will be based on the alternatives generated with the FORPLAN models (Hof and Pickens 1986). The approach to be taken focuses the regional/national analysis on the selection of discrete management alternatives provided (perhaps over a period of years) by the forests (see Wong, 1980; Bartlett, 1974). These discrete alternatives will include scheduled outputs and costs. They, in essence, will be zero-one choice variables in higher level models that could be linear programs or integer programs. A test of this approach is reported in Hof and Pickens (1986, 1987).

This test shows that the Bartlett-Wong approach performs very well in terms of overall optimality--it is able to locate "points" on the global production possibilities frontier with a high degree of accuracy. The Bartlett-Wong approach, however, does not closely emulate a global optimization in terms of forest level output solution values or budget allocations across forests. It is thus much more useful for Assessment analyses than for Program analyses. Given the above-quoted viewpoint that the forest plans and the Program need to be linked, however, this multilevel model may be useful in the Program as well.

It should be emphasized that if forest planning alternatives are to be used in building the Program alternatives (regardless of the method), then a systematically varied set of forest alternatives would be most useful. Beuter and Iverson state:

> "...FORPLAN runs are expensive and, probably too many are being made..."

If forest planning information is to be used at a higher level of planning, then I would take serious issue with this statement. In this context, the purpose of forest planning is not just the development of a "preferred alternative" but the development of a set of alternatives that effectively describe the range of options available. My reaction would be that we probably need more runs (alternatives) not fewer, and if FORPLAN is too expensive to do this then it is a very serious shortcoming. One advantage of modeling a planning problem should be that sensitivity analysis and "what if" exercises are possible. If we can't experiment with the model, its utility is greatly diminished. As an example, the performance of the Bartlett-Wong model is directly affected by the number of and systematic variation in the alternatives included.

Given these conclusions, the Forest Service might eventually consider developing the capability to pursue an approach such as that discussed by Kornai and Liptak (1965). This approach involves a game theoretic model between a higher level planning authority (the "center") and a set of sectoral planning units. The center makes an initial provisional distribution of the "available resources, material, manpower, etc. among the sectors, and at the same time also indicates their output targets." The sectors then rigorously analyze this set of quotas and report back "one type of economic efficiency index--the shadow prices derived from programming." A model such as FORPLAN would be well suited to such an analysis. The center then modifies the resource and output quotas based on this information. By iterating back and forth, a sectoral allocation is arrived at that, within a given tolerance level, equates the shadow prices across sectors and thereby reaches a global optimum. This is a direct type of decomposition of the global optimization problem. To use a Kornai and Liptak type of model, the Forest Service would need to have all forest (FORPLAN) models operational during the same period of time, and communication channels would have to be opened to support the iterations between higher and lower levels. Until this would be possible, the Bartlett-Wong approach has the potential to address at least part of the problem and encourages the general sort of coordination that would be necessary for the Kornai and Liptak approach.

It is also important, if FORPLAN solutions are to be used in any sort of higher level analysis, that consistency between forests is maintained. This includes the definition of outputs, definition of costs, inclusion/deletion of outputs, the definition of time periods, and the definition of alternatives. In this round of planning, it would be difficult to argue that the forest plans are consistent on any of these counts.

One final remark regarding the linkage between FORPLAN and RPA might be worthwhile. Beuter and Iverson correctly assert that, "There is no easy way to translate costs associated with an integrated resource plan into functional budget categories." There is no way to tenably perform this task. Furthermore, Hof and Field (1987) showed that output level decisions based on any of the commonly used methods should be expected to be biased. It would be much more defensible if we were able to base all output level (resource allocation) decisions on joint costs and use cost allocation only for accounting purposes.

Conclusion

In conclusion, I would like to express a philosophy that the purpose of quantitative modeling is not to provide an answer, but rather to serve as a thinking tool and a device for organizing the problem at hand. If this viewpoint were to be accepted, then a model such as FORPLAN would be most useful if the decision-maker(s) were much more involved in its construction and use. If this is organizationally impossible, then perhaps this particular philosophy should be dismissed. However, if the philosophy has some intrinsic merit, then perhaps the agency should accept the challenge of bringing the analysis itself into the grasp of the decision maker.

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The Costs and Benefits of a Forest Planning Model: Discussant's Comments

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Abstract.--This paper focuses on the external economics of FORPLAN. What are the costs and benefits of this particular planning model and the process based around it? It discusses the costs and benefits of the planning system, and concludes by examining alternatives to FORPLAN

An economic perspective on FORPLAN usefully distinguishes internal from external economic questions. Internal economic questions refer to the use of economic concepts and information in the operation of FORPLAN itself. Examples include the estimation of silvicultural costs, derivation of the technical coefficients linking activities to outputs, and determination of the demand for various forest products. These problems are by no means trivial (especially the questions related to demand), but are understood reasonably well. External economics -- the costs and benefits of the planning system itself -- are the focus of this paper.

Costs

As with most problems in natural resource economics, the costs appear far more clearly than the benefits. Six kinds of costs are relevant to an evaluation of FORPLAN.

Analysis Costs

National forest planning is an unmitigated example of what Simon(1979) has called procedural rationality. He argues that the objective of procedural rationality is to find optimal decisions net of analytical costs. The costs of developing the FORPLAN system and the FORPLAN models for each national forest apparently are not known with any degree of certainty, but are thought to be several hundred million dollars. To evaluate the planning system, these costs must be calculated. Such a summary has been requested by Congress for the national Resources Planning Act Assessment and Program (RPA). A similar accounting should be made for the planning activities promulgated under the auspices of the National Forest Management Act (NFMA).

Beuter and Iverson ask if FORPLAN will lead to better decisions. Because all national forest planning relies on FORPLAN, there is no way of wholly answering this question. However, better decisions must, by definition, differ from past ones. Beuter and Iverson's question can then be partially answered by determining if FORPLAN has resulted in decisions which differ from the ones made under earlier planning systems. Little evidence has been presented on this point. Schweitzer et al. (1986) argue that current decisions probably differ little from past ones because "there are powerful forces in the forest planning process that influence most forest plans to be similar to traditional types of forest management." (p. 10). If the use of FORPLAN is not altering forest management decisions, then this costly planning procedure does not achieve Simon's desideratum for procedural rationality.

Suppose that FORPLAN represents overinvestment in analysis. What, then, is the optimal amount of analysis? The "Max-Loss" procedures developed by Navon et al. (1986) offer one approach for addressing this question. Rows and columns of the FORPLAN matrix can be aggregated, and a bound on the loss of efficiency resulting from the aggregation can be calculated. In their sample problems, the loss in efficiency was very small even with large reductions in problem size. Thus, in large FORPLAN models the marginal costs of increased complexity probably exceed the marginal benefits. Economic efficiency would be served by reducing model size.

My own, limited experience with FORPLAN suggests that the net present value surface may very flat near the optimum; many different management plans have very similar economic performance. These different management plans may have quite different political implications. Rather than simply solving every FORPLAN problem to optimality, the analytical effort would more usefully be directed towards identifying all the plans which are "nearly" optimal.

Institutional Costs

The use of FORPLAN excludes important people from the national forest planning process. That the general public cannot understand FORPLAN is by now obvious. A public excluded is a public prone to litigation. This fact results in a central paradox of applying the rational planning paradigm to the national forests: if the public participates effectively in the planning process, the results are necessarily politically determined; if the public is systematically excluded from the planning process, the process will be subverted by legal challenge. In either case, politics, not rational planning, determines the outcome.

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FORPLAN apparently also excludes people within the Forest Service from participating in forest planning. Votyas (1986), a Deputy Forest Supervisor on the Ottawa National Forest, commented on that Forest's plan:

> Because of the speed necessary to develop and complete the Ottawa National Forest Plan,...we had to...exclude some people from the analysis process. Some district rangers and Forest staffs didn't have the time or personnel or perhaps finances to get as deeply involved as they probably should have. I'm sure some didn't have the interest or motivation or knowledge as well. Maybe some were turned off by the complexity and sophistication of the FORPLAN model...some Forest and District people were left in the dust, so to speak. They were unwilling, or unable or not permitted to keep up with the planning process. (p. 119-120)

Through this tendency for selective exclusion, the use of FORPLAN in national forest management planning inevitably affects the internal organizational structure of the Forest Service. For example, one might hypothesize that FORPLAN is a tool for the timber management interests within the Forest Service to regain some of the ground they lost during the past decade. Bits of evidence support this hypothesis. For example, in their review of the history of FORPLAN, Iverson and Alston (1986) note that FORPLAN was acceptable to the agency only because of its roots in harvest scheduling optimization. As another example, I once visited a national forest in the midst of a forest planning crunch. Their FORPLAN model was not functioning as expected, and they needed help. Who was contacted? The Timber Management Staff in the regional office!

The longer term changes in the structure of the Forest Service which have been induced by FORPLAN are likely to be rather subtle. For the researcher in organizational behavior, it might be useful to follow the careers of the planners, operations research analysts and economists hired during the first round of NFMA planning. Will they rise through the ranks to become district rangers and forest supervisors? Or will the agency's immune system isolate them?

Increased Centralization

The 1979 directive requiring all national forests to use FORPLAN shifted power upward in the classically decentralized Forest Service. Increasing the degree of central control, while tending to standardize plans, limited on-the-ground testing of alternative analytical approaches to the forest planning problem. Neither FORPLAN nor its immediate predecessors were vetted through the normal research procedures of peer review and publication. Because FORPLAN had not received the benefit of "research" in the normal "research and development" process for creating new methods, the Forest Service would have been served well by the kind of exploratory work which would have occurred on individual national forests under a less centralized planning system.

Traditionally the management plans for individual national forests have been negotiated locally among local interest groups. The exceptions have been rare and notably so: the Bitterroot and Monongahela National Forests, for example. The shift to a procedurally complicated, technically complex, standardized planning model has made the management practices on individual national forests easier targets for the powerful centralized critics--the Office of Management and Budget, and the national interest groups such as the National Forest Products Association and the Wilderness Society. The Wilderness Society has been particularly effective in using the increased centralization to its own advantage. Once the complexities of FORPLAN have been mastered, the cost of analyzing another forest plan is low. The scale economies of knowledge associated with a standardized planning process inevitably favor the national interest groups over the local ones.

Elsewhere in this symposium others have argued that FORPLAN has served to shield the Forest Service from its critics. Where the critics do not have the technical capability, time or money to master FORPLAN, perhaps this is so. But once the key to the central defense is discovered, the shield no longer serves well. A diversity of planning methods would be a better, more permanent defense, particularly from the national interest groups to whom the Forest Service is most vulnerable.

Increased Ignorance?

Mathematical models exclude some considerations so that other aspects of a problem can be treated with great clarity and precision. This systematic exclusion of information is precisely the value of quantitative approaches to management and policy analysis. Yet this characteristic also produces the risk of Beuter and Iverson's "mathematical aphasia," or what is less eloquently known as a Type III error--solving the wrong problem. During the past three decades of large-scale social science modeling, the analytical landscape has become littered with modeling efforts wrecked by failure to include some important phenomenon. What important information does FORPLAN systematically exclude?

Systematic exclusion of information in planning results in a more limited capacity to respond to future change. Because the future is inherently unknowable, some attention should be paid to "surprise rich" scenarios. By their very nature, such scenarios may be difficult to quantify: there is no historical record on which to base the conventional analyses. Data are history, but planning is about the future. Too great a reliance on quantifying the past increases, rather than reduces ignorance about the future.

Planning in a Vacuum

Beuter and Iverson emphasize my fifth point: the current forest management planning process focuses on individual national forests without consideration of adjacent lands. This inevitably results in suboptimal social solutions to forest sector problems.

The best solutions may lie outside the national forests. For example, the Pacific Northwest Forest Policy Project (Bruner and Hagenstein 1983) showed convincingly that a coordinated public-private action was more successful in achieving a stable regional timber economy than was federal action alone. As another example, to serve the demands for outdoor recreation in New England, it may be more effective to improve state and local parks near the population centers than to develop more capacity on the White and Green Mountain National Forests. Yet national forest management planning explicitly excludes consideration of such alternatives.

The State and Private Forestry (S&PF) branch of the USDA Forest Service has suffered hard times recently. A conservative administration abandoned S&PF's historical mission of subsidizing timber production on private lands. An alternative, useful role would seek out those occasions where the best solutions to national forest problems lie on private or nonfederal public lands.

Implementation

Plan implementation carries many difficulties. Beuter and Iverson note the unrealistic budgets coming out of the current round of forest planning. Plans are implemented through budgets. What is the use of planning for a budget which is unlikely to be funded? At least some analytical effort should be devoted to exploring alternatives where the budget is constrained to realistic levels. This problem also occurs in the national RPA plans.

Optimal forest plans do not simply "scale down" in response to budget constraints. That is, the optimal mix of program elements will shift as increasingly strict budget constraints are imposed. At a high budget level, the optimal plan might call for much recreation. As the budget is lowered, the optimal program mix might well be skewed towards a larger emphasis on timber.

The gulf between assumed and actual budgets is not the only impediment to implementation. Other model assumptions may be at variance with reality. For example, the marginal willingness to pay for recreation on national forests is, by definition zero unless a user fee is levied. In a linear programming framework, a positive value for recreation must be used to insure that, on average, the land allocations are correct. But any prescriptions which call for additional recreation investment will be correct only if a fee equal to the assumed marginal willingness to pay is actually levied. Otherwise, what guarantees that the recreationists who value the new facility are the ones who use it? The same problem would arise if a FORPLAN simulation valued timber at $150/mbf; but management practice gave timber away at no cost.

Benefits

So, the costs of NFMA planning in general and FORPLAN in particular seem large. What are the benefits? Beuter and Iverson point out that the theoretical objective of FORPLAN is economic efficiency: to maximize net present benefits subject to constraints describing forest production possibilities, environmental regulations, and legal requirements. Haigh and Krutilla(1980) go further to describe economic efficiency as a requirement of the National Forest Management Act. Does FORPLAN achieve this objective?

Partially. FORPLAN is apparently effective in eliminating prescriptions which are not cost-effective. This is no small task. But the larger objective of overall economic efficiency is not always served. Even where economic optimization is given free rein in FORPLAN, the resulting plan is unlikely to be selected as the preferred alternative. Others in this symposium have stressed the utility of FORPLAN as a simulation tool. If simulation is the objective, then linear programming is a poor analytical approach, and the principal benefit of linear programming--identification of economically efficient plans--is lost.

While economic efficiency might underlie NFMA, reconciliation of political discord was an overriding objective of the new planning procedures. The Giltmeir Index--the number of lawsuits filed against the Forest Service on matters of policy and management--is a useful measure of how well the Forest Service has achieved this objective. The definitive statistics have not been compiled, but Giltmeir (personal communication) reports that the Index is probably down as administrative appeals have supplanted formal legal challenges. Perhaps the Giltmeir Index will rebound as these appeals mature into court cases, or perhaps it will remain quiescent as controversies are reconciled through administrative channels.

The long-term success of NFMA planning in reconciling discordant visions of the national forests remains unproved. Earlier in this symposium, two Forest Supervisors--Orville Daniels and Steve Mealy--gave optimistic views. Because FORPLAN is essentially a nonincremental, "zero-based" planning model, all the tough decisions surface at once. As a consequence, political discord peaks during the period when the plans are being prepared. Optimistic views of the planning process presume that the decisions forged during this contentious period will hold together throughout the planning cycle, and thereby the discord will be reduced over the longer run. Is this optimistic view warranted? The next decade's performance of the Giltmeir Index will provide part of the answer.

If Not FORPLAN, What?

Some trace the origins of cost-benefit analysis to Benjamin Franklin. Faced with a decision, he is supposed to have listed the costs in one column and the benefits in another, and decided according to the relative lengths of the two columns. Using this criterion, I am reluctantly skeptical about the net benefits of FORPLAN.

This begs Beuter and Iverson's final question: "If not FORPLAN, what?" They argue that FORPLAN, or something very much like it, will occupy a central place in forest planning for quite some time. I agree. Sunk costs, so capriciously dismissed by economists, weigh heavy on administrators. Long bureaucratic memories and sheer institutional momentum guarantee happy pasture for formal planning models such as FORPLAN. A relevant question is how to improve the utility and performance of FORPLAN. Here, I have two suggestions.

First, because FORPLAN is a market-like model, make greater use of market-like incentives. In the management of the national forests, for example, levy fees for recreation and wilderness use (Binkley and Mendelsohn 1987 discuss the advantages of using fees in outdoor recreation management). Imposing recreation user fees would bring management reality into concert with the economic assumptions behind the forest plans. Imposing fees would generate believable estimates of the value of recreation. Most important, imposing fees could create new revenues for the Forest Service. These revenues could fund the many, high economic return recreation investments which apparently exist on the national forests (Binkley and Hagenstein 1986).

Similarly, use market-like incentives in the forest management organization. In a 1981 Resources for the Future conference on management of the national forests, I proposed that each national forest be organized as a profit center in the accounting sense (Binkley 1983). Where they exist, use market prices to value the inputs and outputs associated with management of the forest; where market prices do not exist, impute surrogate prices. Pay the forest supervisor, district rangers and others of the forest according to the annual net surplus. To do so would require a set of accounts which would separate legitimate capital investments from operating expenses. By themselves, these accounts would help in analyzing some of the current national forest management controversies such as the so-called below-cost timber sales problem. If economic efficiency is an objective of using FORPLAN in NFMA planning, then market-like incentives in management and organization would surely help achieve it.

Second, do needed research on land management planning. The usual research and development processes were not followed in developing FORPLAN. There apparently was little peer review, and no peer-reviewed publication of the model as it was developed. Those outside the immediate circle of developers had little access even to the grey literature on the model. Lack of participation by the wider research community, particularly the research division of the USDA Forest Service, is surprising. Three areas seem to warrant particular attention in future research on land management planning:

i. Analysis of the analytical process itself. What were the costs and benefits of the first round of planning? How did actions change in response to land management planning?

ii. Institutional factors. How did the Forest Service change in response to FORPLAN? What kinds of information were systematically ignored because of the modeling efforts? How can this information be brought back into the planning process? What are the limits of procedural rationality in national forest planning? How much technical information can be transmitted via the political system?

iii. Large-scale modeling systems. Beuter and Iverson usefully distinguish model efficacy from model efficiency, pointing out that the first implementation of any system is not likely to be very efficient. But now it is time to turn to questions of efficiency. Can the recent advances in solution algorithms for linear programs--Karmarkar's algorithm, gradient projection techniques,...--be usefully exploited in the kinds of problems which arise in land management planning? Are there fast heuristics to take advantage of any special model structures typical of FORPLAN problems?

Formal, quantitative modeling has a role in planning, managing, and developing policy on the national forests. Much work remains to exploit the full power of formal analysis. Given the size and importance of land management planning, research on the technical and institutional aspects of the problem should be expanded.

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An Ecological Evaluation of FORPLAN in National Forest Planning

H. H. Shugart and Bradley J. Gilbert[1]

Abstract.--This paper evaluates the software package used to formulate linear programming models for use in forest planning (FORPLAN) from an ecological perspective. The evaluation centers on three major topics: (1) philosophical criticisms of the FORPLAN approach, (2) technical considerations when modeling ecological systems using FORPLAN, and (3) improving the ecological content of the FORPLAN system.

The FORPLAN system (Johnson 1986, Johnson et al. 1986) is a very large (and complex) algorithm. The FORPLAN versions 1 and 2 and their antecedents represent an attempt to quantitatively deal with the myriad of problems that arise from attempts to maintain forests as productive ecosystems for multiple-valued goals (money, recreation, wildlife, endangered species preservation, etc.) over a long period of time. To say that the management problems that attend such an assignment are difficult is to understate the problem. The entire development of the quantitative approach to this problem is itself the topic of interesting historical accounts (Jones 1986, Iverson 1986). The approach that will be taken in this paper will be to evaluate the FORPLAN System's ability to model ecological systems from the point of view of an ecologist outside the Forest Service. Three topics will be treated in this discussion:

1. Philosophical criticisms of the FORPLAN approach.
2. Technical considerations when modeling ecological systems using FORPLAN.
3. Improving the ecological content of the FORPLAN system.

Several (if not all) of the points that will be raised undoubtedly have been considered and put aside for one reason or another by people in the Forest Service and probably by the very able team that has developed the FORPLAN code. Whenever possible, examples from the field of ecological modeling will be used in the discussion of these various points. FORPLAN might be viewed as a lump of clay, available to be molded into many different shapes based upon the desires of the sculptor. It could be used to model aspects of ecology yet undreamed of by users. However, this paper will focus on the use of FORPLAN as an analysis tool in the existing forest planning process (Forest Service Manual Chapter 1900). We will not try to compare FORPLAN against alternative analysis tools that may have been or may be used in the future. Nor will we speculate on hypothetical planning processes which may have used FORPLAN in a context other than as a land allocation and activity scheduling tool. Rather its adequacy as an ecological analysis tool will be evaluated.

PHILOSOPHICAL CONSIDERATIONS IN USING LARGE MODELS

In reading the comments on the vices and virtues of the FORPLAN model (Bailey 1986), clearly, some of the arguments arise from what are differences in points of view. This is not to trivialize these arguments because often these differences have their bases in philosophical views about modeling processes. Also, many of these positions are not unique to FORPLAN but have been a part of discussions about other ecological modeling efforts.

DISTRUST ARISING FROM MODEL COMPLEXITY

Large models generate distrust among some members of almost any scientific community. For these scientists, large models seem to be a contradiction to the "Ockham's razor" principle of parsimony that is the basis for much of western science. Even without a more parsimonious explanation, many scientists are likely to be suspicious of the scientific rigor of any very complex explanation.

The general distrust of large models is in no way unique to the FORPLAN model. For example, the International Biological Program was regularly bombasted on the basis that the computer models that it was developing were overly complex and thus non-scientific (Watt 1975). It is fair to say that a segment of the scientific public will simply not be attracted to large models and that their position is historically quite defensible in terms of the development of modern science. The position on this issue taken by so many of our peers sets a strong priority on demonstrations of the effectiveness of large complex models over other approaches. It is harder (in the sense of model validation) to push a complex model to a given level of scientific acceptance than it is for simpler, more theoretical, models.

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A point that is related directly to the size of models and to pragmatic considerations involves the propagation of errors in model parameters and the reliability of the data in large sets of input data. The experience in most ecological modeling exercises has been that models of intermediate complexity have normally had the greatest forecasting ability (O'Neill 1975). This can be attributed, in part, to the fact that almost all parameters in ecological models have error in their estimates. It is a nontrivial problem to identify whether it is a worse error to leave out a given feature in a model rather than include it when there is error in estimating the parameters associated with its incorporation in the model. In most ecological models, this problem cannot be solved by a rule of thumb. Most sensitivity analyses of large models focus on a few parameters that appear to be the dominant factors for a given model application. One might presume (as has been done regularly) that if the error in the more sensitive model parameters is under control then the model predictions will be reliable. In cases in which the model is being used to interpolate system dynamics this may well be true, but the potentially dramatic impact of model structure on sensitivity analysis must be kept in mind.

DIFFICULTY IN COMPARING INTUITION AND MODEL RESULTS

Somewhat related to the sorts of considerations just mentioned concerning large models is the difficulty in being able to develop an intuitive understanding about why a model produces a given result. This criticism places the model developer in a rather difficult position in that large models are often developed specifically to investigate problems for which there is no intuitive solution. Even if this criticism attacks the model for doing exactly what it was designed to do sometimes,a real problem is that users distrust models that produce answers which are hard to infer from the causes. The solution of the problem probably lies in exercising the model to the extent that the user is more familiar with the inner workings of the algorithms, but this approach involves the user learning a lot about the model but not necessarily a lot about reality (Barber 1986).

COMPUTER COSTS INVOLVED IN RUNNING MODELS

Large models are often expensive to run on computers or at least appear expensive to the non-computer aficionado. This is the case with implementations of the FORPLAN model on more complicated problems. The cost of computer time is something of a red herring in that the cost of conducting research under field conditions (at least in the ecological sciences) is usually larger than these computer costs by a great margin. This is the case even when the data collection is justified by a model development goal. The criticisms relating to model complexity just discussed have as their solution more frequent implementation of the models on computers. If one would like to do sensitivity tests, to determine the effects of data error structures on model performance, or even allow a model user to become more familiar with the model behavior, it follows that there will be more computer time spent on the models to accomplish these goals.

TECHNICAL CONSIDERATIONS WHEN MODELING ECOLOGICAL SYSTEMS USING FORPLAN

THE ECOLOGICAL IMPLICATIONS OF THE NATIONAL FOREST MANAGEMENT ACT

Before one can evaluate any model there must be a basis upon which to judge the value of the tool. In this instance, it seems most fair to judge the FORPLAN model against Section 6 of the National Forest Management Act (NFMA). One might argue that the regulations also provide a basis for judgment, but they are one step removed from the act itself and embody extensive interpretation. Also, the regulations may have been written with a particular tool in mind, thereby imparting some bias in their requirements. Therefore, we will use the act alone as the anchor for the evaluation.

The principal points made in Section 6 of the National Forest Management Act concerning ecology can be summarized succinctly. NFMA Sec. 6 (e)

> "(1) provide for multiple use and sustained yield of the products and services obtained therefrom in accordance with the Multiple-Use Sustained-Yield Act of 1960, and, in particular, include coordination of outdoor recreation, range, timber, watershed, wildlife and fish, and wilderness; and
>
> "(2) determine forest management systems, harvesting levels, and procedures in the light of all of the uses set forth in subsection (c)(1), the definition of the terms 'multiple use' and 'sustained yield' as provided in the Multiple-Use Sustained-Yield Act of 1960, and the availability of lands and their suitability for resource management.

NFMA Sec. 6 (g)(3)

> "(A) insure consideration of the economic and environmental aspects of various systems of renewable resource management, including the related systems of silviculture and protection of forest resources, to provide for outdoor recreation (including wilderness), range, timber, watershed, wildlife, and fish;
>
> "(B) provide for diversity of plant and animal communities based on the suitability and capability of the specific land area to meet multiple-use objectives, and within the multiple-use objectives of a land management plan adopted pursuant to this section, provide, where appropriate, to the degree practicable, for steps to be taken to preserve the diversity of tree

species similar to that existing in the region controlled by the plan.

Another major feature can be summarized as a concern for environmental protection. This can be seen in the inclusion of requirements for reforestation, limitations on suitable acres for timber harvest, and an admonition to identify and recognize potential hazards. It is interesting to note that economics is only briefly mentioned in Section 6 of the NFMA (Sec. 6 (g)(3)(A)).

ANALYTICAL IMPLICATIONS OF THE NATIONAL FOREST MANAGEMENT ACT

What then are the analytical implications of these ecologically related points? The references to the Multiple-Use Sustained Yield Act simply lay a foundation upon which to build improved forest management. From an analytic standpoint the major implication is that one must be able to consider sustained yield of all multiple-use products and services.

The Forest Service is also directed to coordinate all resource management. On the surface this may not seem to be more than an elaboration of the multiple-use concept. However, upon further investigation of the meaning of "coordination" as used in the Act, one finds that there are significant ecological implications. Coordination implies to make of the same order or importance. In terms of resource management and as used in the act, "coordination" implies that no resource may be emphasized to the degree that minimum requirements for any other resource are violated (Salwasser and Mealey 1983). This direction from Congress has significant implications for forest planning analysis. Specifically, it implies that what has come to be called minimum management requirements must be portrayed in the analysis.

Section 6 (e) (2) requires some method be used to choose among alternative management systems based on their economic and environmental effects. Considering economic and environmental effects of management systems implies the ability to show not only simple effects, but the interactions among the managed resources. To understand the resource interactions is to understand the ecological processes upon which they are based. The challenge is to be able to estimate the ecological effects of resource management at the geographic scale of a national forest.

Perhaps the most explicitly ecological requirement of the act is in the phrase "provide for diversity of plant and animal communities..." Section 6 (g)(3)(B). Although the interpretation of the term diversity is problematic, an operational definition has evolved and has been incorporated in the NFMA planning regulations: "the distribution and abundance of different plant and animal communities and species within the area (a National Forest) covered by a land and resource management plan." (36 CFR 219.3). The important implication for the analysis is that this requires that both the distribution and abundance of plant and animal species be considered. No requirement to model this information was specified, but one can well imagine that satisfying this requirement has caused the Forest Service considerable head scratching.

Probably one of the key concepts to be found in the NFMA is the notion of integrated management, trying to capitalize on symbiotic relations that exist in nature through management. This in turn makes the examination of ecological interrelationships a critical part of the forest planning analysis. When one adds to this the environmental and productivity protection language woven through the act, apparently both the positive and negative effects of management choices must be considered. These positive and negative effects run the gamut from simple relationships, such as the quantity of wood fiber harvested, to complex cases of determining the effects on the viability of a wildlife population. Such diverse requirements pose problems for any single analysis tool. These problems are compounded when such diverse relationships must also be portrayed over an area the size of a national forest, most of which are over a million acres in size. Fortunately, there is no requirement in the NFMA to use any particular analysis tool, nor is there a limitation on the number of tools that can be used. However, given all the analytic requirements in forest planning, there is an intuitive appeal in minimizing the number of analytic steps required.

A couple of additional points need to be made about the analytical implications of the NFMA before further developing the ecological evaluation of FORPLAN. First, both protection and dealing with hazards can be viewed proactively and reactively in forest planning. The proactive view holds that management activity can help protect and enhance the productive capacity of the land. Similarly, many potential hazards can be avoided or reduced through knowledgeable management. The reactive view is to handle protection through constraints on management activities, both in terms of mitigation and preservation to protect and avoid hazards. Both views have their place in forest planning analysis, and the analysis tool used should accommodate both approaches. Second, the requirement to provide for diversity of animal and plant communities is a major ecological requirement. Diversity was chosen as a proxy for many ecological considerations. When the act was written it was commonly held among ecologists that increased diversity in ecosystems led to increased stability. Including diversity in the act was also a way to combat extensive vegetation-type conversion, which was a motive in the creation of the NFMA. Since that time, the science of ecology has progressed and more factors than diversity have been identified as contributing to stability.

THE BASIS FOR THE EVALUATION

In evaluating FORPLAN, it is important to understand that there are three possible dimensions to the discussion. The first dimension relates to the fact that a linear programming algorithm is used to solve the models created by the FORPLAN matrix generator. The second dimension pertains to the actual models created on a particular National Forest using FORPLAN. The third dimension is FORPLAN itself, the matrix generator and report writer, which are used to create the models which are, in turn, solved using linear programming. There are interactions among the three dimensions. However, every effort will be made during the evaluation to keep the distinction clear about which dimension of FORPLAN is being discussed.

The approach that will be used to evaluate FORPLAN will be to examine facets of ecology which must be addressed if the intent of the National Forest Management Act is to be met. The ecological facets which will be examined are:

1. Non-linearities in Ecological Relationships.
2. Variations in Ecological Time Scales.
3. Multiple Resource Interactions.
4. The Spatial Dimension of Ecological Relationships.
5. Variation and Error in Model Coefficients.
6. Uncertainty in Ecological Processes.
7. Succession and Mortality.
8. Dynamic vs. Static Representations of Ecological Processes.
9. Vegetative Structure.
10. Delineation of Land Units for Analysis.

The facets that have been chosen for examination are the most significant and challenging in terms of successfully modeling forest dynamics. Where appropriate, we will discuss how FORPLAN deals with each facet and the problems that arise. Also, approaches used to solve or circumvent the problems will be addressed. During the evaluation it will be noted where problems stem from the assumptions of linear programming as opposed to problems created by the FORPLAN matrix generator and report writer.

Non-linearities in Ecological Relationships.

The use of linear programing as the algorithm in the FORPLAN model has attendant assumptions about the linearity of the problem. Linear programming has its best applications in problems in which the optimal solution locally is also the globally optimal solution or in which one is interested in making small changes in a management strategy that is already near a local optimum. Problems with regards to these and other linearity assumptions lead to the use of nonlinear optimization procedures.

There is considerable debate in ecological sciences about the linearity, or lack thereof, in ecosystems. In a practical sense, many non-linear relationships can be adequately represented by linear approximations, particularly non-linear functions of time. Even here, non-linear responses from management activities that alter internal system dynamics can be very difficult to represent. An example is road building. A watershed may tolerate road building up to a point beyond which catastrophic erosion may take place (an internal change). This sort of relationship is difficult to portray in a linear programming model because it violates one of the implications of the linearity assumption; that of proportionality. Another example of this sort of difficulty is attempting to model wildlife habitat capability. Efforts have been made to incorporate a habitat capability model which is a non-linear function of the age class distribution of the vegetation into a FORPLAN model (Holthausen 1985). It is possible to track the age class distribution of stands in the model, but it is not possible to dynamically calculate the habitat capability index, even if it could be linearized, during the model execution. For Holthausen (1985), the habitat capability index was calculated outside the model execution and therefore biologists were unable to use it as an objective function in the model.

An alternative approach is available to allow habitat indices to be incorporated into the model. This involves delineating a geographic area in FORPLAN, specifying the anticipated age-class distribution of the vegetation and calculating the habitat capability index as it changes through time outside of FORPLAN, and then entering the resulting yield stream into FORPLAN. This would represent one possible choice for the area in question and the same procedure could be repeated for other choices. A similar approach could be used for the road example.

Variations in Ecological Time Scales.

Some ecological processes have rapid dynamics. For example, certain pest outbreaks may run through a complete cycle in less than 10 years. Some wildlife species complete an entire life cycle in a year. Trees, however, typically require over a century to reach maturity. Different time scales for the dynamics of system elements make model development difficult and, therefore, have plagued modelers. The problem is often resolved by selecting a timeframe of interest and then attempting to include those processes with the ability to respond dynamically in the timeframe in the model. Another approach is to represent different model components at different time scales. This approach has the potential to add complexity to an already complex analysis and is not often used by forest analysts.

In developing forest management plans, it is agreed that the analytic investment should be placed on the near term where there is the most payoff. This argues for smaller time steps in the short term and longer time steps in the long term. However, this is not as easy as it seems given the requirements of the NFMA on how the timber analysis must be conducted. FORPLAN model size can be attributed in part to these requirements. Nevertheless, FORPLAN has capabilities to reduce the number of constraints in the models by allowing time periods late in the planning horizon to be combined into intervals.

Multiple Resource Interactions.

Linear programming techniques function to optimize a problem concerning a single commodity (an economic criterion such as present net value (PNV) is commonly used in FORPLAN models) subject to some constraints. Attempts to include the economic value of nonmarket resources is not always well received because of the difficulties in establishing mutually agreeable willingness to pay estimates. Furthermore, the focus on economic objective functions undoubtedly raises the ire of environmentally oriented users of the model in that it tends to put certain values (recreation, wildlife, water quality) in the defensive position of constraining the economic productivity of the nation's forests.

The situation is more than simply a semantic matter arising from "constraint" being a somewhat pejorative term (particularly when one is constrained from making money). The objective of Forest Service management strategies is to optimize multiple-use of the nation's forests. It is not at all clear that the management strategy for optimizing money developed by using the FORPLAN model under a constraint of maintaining a given level of animal species diversity would even resemble the optimal strategy for optimizing diversity under the constraint of producing a certain cash flow. If the choice of the single commodity used in the model influences the development of the multiple-use optimal strategy, it may well be appropriate to investigate the sensitivity of model output to this feature. An approach to accomplishing this is provided by Dress (1982). Although Dress advocates using a goal programming formulation to generate alternatives, this does not appear to be a requirement for the general approach. Forest Service policy requires a benchmark analysis which is very similar to the methodology outlined by Dress. Separate FORPLAN models are run with an objective function representing each of the significant resources on a forest. The results from the runs establish a decision space within which all alternatives must lie. The only problem with this approach is that it is difficult to insure no inferior alternatives (solutions where one or more of the resources could be improved with no cost to the others) are used in decision making because of the number of dimensions in the decision space.

Spatial Relationships.

Spatial relationships are critical to the understanding of ecological processes and, therefore, to their management. The juxtaposition of wildlife forage, hiding cover, thermal cover and birthing areas are critical to the viability and productivity of local populations. Similarly, contagion factors are critical in determining the extent and severity of many insects and disease. Because entering such detail in Version 1 of FORPLAN often led to enormous models, early FORPLAN models often lacked much spatial content. Instead, early models had homogeneous analysis areas scattered across the National Forest with per acre coefficients (Strata-based approach) (Johnson et al. 1986). Enhancements available in Version 2 make it possible to enter both the costs of management specific to an area, such as road costs, and the effects of management on an area; especially ecological effects such as vulnerability to a pest outbreak and sediment production including the consequential effects on aquatic wildlife. This capability is provided by a second level of stratification imposed upon the more traditional homogeneous analysis areas (Mixed strata-based, area-based approach (fig. 1) (Johnson et al. 1986). Although this is a major step forward, it comes at the expense of increased model complexity (there are now two levels of stratification and two types of prescriptions) and not all spatial problems are solved. For example, if site specific detail on the timber harvest schedules are desired then model size can still be a problem.

Difficulties in representing the spatial facet are primarily attributable to the size of National Forests which are being modeled. Both FORPLAN and linear programming have the ability to model rather intricate spatial relationships (See the paper by Ryberg and Gilbert (1986) for an example of using FORPLAN to represent spatial relationships). However, some uneasy compromises have been forged in attempts to incorporate spatial content into forest-wide models.

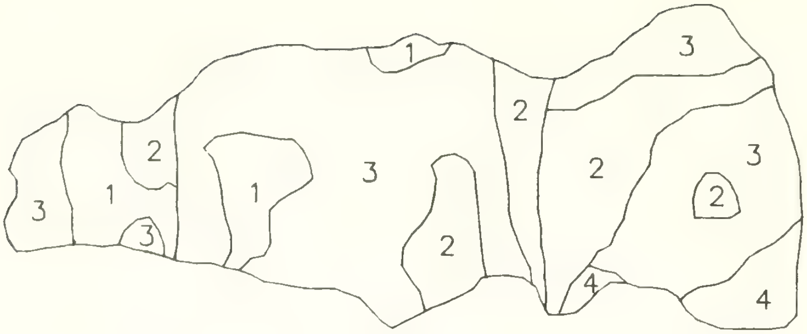
Variation and Error in Model Coefficients.

A significant question in the development of ecological models is how to deal with great variability and error in coefficient estimates. Not only do individual populations of flora and fauna generally posses wide ranges of variability, but there is also a wide range of variability between different populations. For example, some timber stands may be very homogeneous, and if you compared stands of the same species on similar sites they would have similar variability (Moeur 1983). But, wildlife living in the same stands could vary dramatically in number because of some small-scale habitat requirements such as snags, fallen decaying trees, and berry producing understory shrubs (Shugart and Urban 1986). The question then becomes, should coefficients with such different variability be included in the same model and if they are, what are the effects on the solution, both in terms of resource outputs and land allocations? A similar question can be raised about error in coefficients.

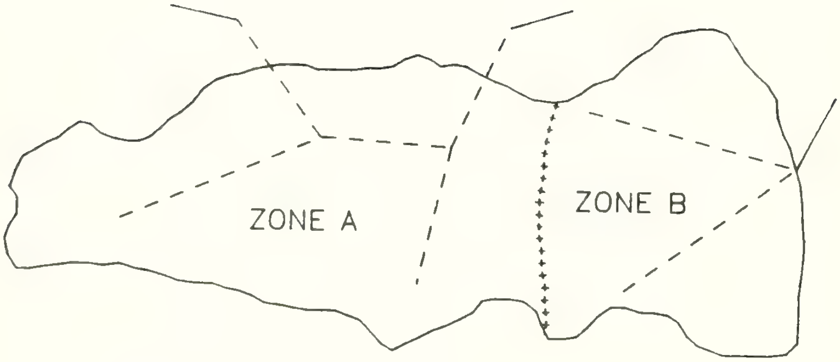
Methods for circumventing this problem are to improve data, refine the land stratification to reduce variability, and leave variables with high variability or error outside of the model. Those variables left outside the model must then be incorporated into the alternative evaluation and selection process by other means.

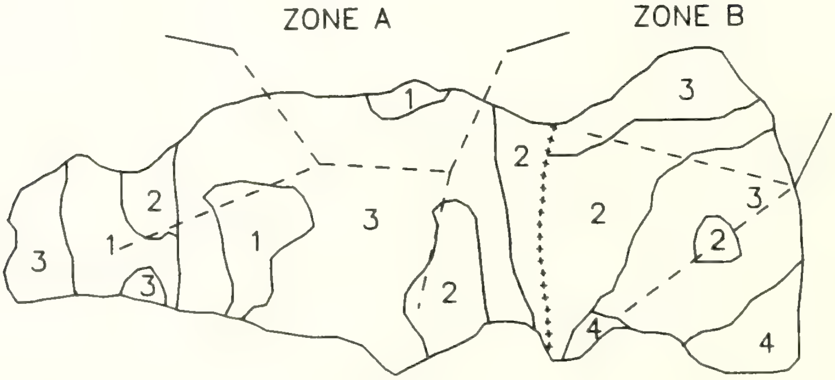
Uncertainty in Ecological Processes.

One of the major difficulties in modeling ecological systems is providing realistic representations of uncertain events. Unpredictable diseases can affect both animal populations and their habitats. Natural disasters, such as floods, fires, and volcanoes can cause major changes in the environmental structure. Ecological studies have helped managers understand that some "disasters," such as fire, may have the beneficial effect of rejuvenating successional communities. No matter what analysis procedure is used, the real burden of dealing with uncertainties falls on the decision maker who must determine how much risk he or she is willing to accept.



Strata	Definition
1	Loblolly pine seedlings and saplings
2	Mixed hardwood poles
3	Loblolly pine mature
4	Meadow





Analysis Area	Age	Acres	
		Zone A	Zone B
1	5	200	0
2	15	150	150
3	35	450	250
4			100

++++++ RIDGE

——— EXISTING ROAD

– – – PROPOSED ROAD

Figure 1.--Maps which illustrate the concept of a dual stratification called a mixed strata-based, area-based approach (Johnson et al. 1986).

Models differ in their abilities to unravel the uncertainties embodied in ecological processes. Three different schools of modeling: optimization, simulation and control theory, all have methods for handling uncertainty (Bare and Schreuder 1976, Walters and Hilborn 1978). Usually, the analysis becomes more complex and less feasible for large problems. As a result, one must weigh the benefits of including uncertainties against the costs of increased complexity. One noteworthy example of considering risk with FORPLAN is the application to the problem of population viability used by Salwasser et al. (1984). Salwasser et al. (1984) estimated the habitat requirements necessary to sustain a viable population of a wildlife species at a prescribed risk level outside of FORPLAN. Then constraints were added to a FORPLAN model to insure the required habitat was part of the solution for each alternative. Higher levels of habitat could also be an objective in wildlife or amenity alternatives.

Another tack is to acknowledge that the coefficients in the LP represent the potential for resource production. An example, is the use of harvest dispersion constraints. Typically, these constraints are imposed over a large area and limit the rate of harvest to a level which provides the potential to lay out cutting units without creating openings which exceed the minimum management requirements. It is then left to the people who carry out the plan to determine whether the desired results can be achieved.

The dilemma is deciding how much detail should be carried in the forest planning analysis tool and how much should be handled in separate steps. On the one hand, as more capability has been added to FORPLAN, it has become more complex to understand and use. However, if pieces of the analysis are handled outside of FORPLAN, then one must learn an additional system and deal with suboptimality issues. Perhaps a happy medium can be found to resolve this dilemma.

Succession and Mortality.

Succession plays a vital role both in modeling growth processes and in the classification of lands for the stratification process. Vegetative treatments and natural processes (fire and other disturbances) have the potential to reset succession with important management consequences. Successional stages at the beginning of the planning horizon are well portrayed in most FORPLAN models. Most FORPLAN model users develop age dependent relationships to help track characteristics of the vegetation deemed important from an ecological and management standpoint. It would be very helpful if the FORPLAN model had more inherent capability to track different successional stages. This would likely result in more consistency among National Forests and would also relieve some of the modeling burden from the analysts. However, this would be difficult to standardize in a general purpose tool such as FORPLAN which is used across all National Forests.

The importance of succession and mortality has been recognized by the developers of FORPLAN. An approach for dealing with this important ecological process has been developed (Johnson and Stuart 1984) and will be incorporated into Version 2 next year. The approach taken is a generalization of the Model 2 structure that has always been a major component of Version 1 of FORPLAN (Johnson and Crim 1986). It will provide inherent capability to examine such forest dynamics as differential regeneration success, stand mortality and a general decision tree approach. This capability will extend the Model 2 structure and should greatly enhance FORPLAN's ability to more realistically represent forest dynamics including probabilistic outcomes. However, these options will have to be used judiciously, otherwise model size and coefficient density could be a problem (Johnson and Stuart 1984).

Dynamic Versus Static Representations of Ecological Processes.

A major concern when using a static model such as linear programming is the inability of the method to represent dynamic ecological processes. Many authors have suggested alternative ways to approach forest dynamics such as simulation and dynamic programming (Bare and Schreuder 1976, Jameson and Bartlett 1986). The well known problem of dynamic programming being unable to handle very many variables prevents it from being a serious contender. However, simulation models have proven to be capable of representing forest dynamics (Boyce 1978, Shugart 1984, Stage et. al 1986). The approach often used in forest planning is to use simulation to predict the ecological dynamics, and then to use the predicted yield streams as components of the decision variables in FORPLAN models. Another aspect to consider is that many dynamic programming problems which meet the proper assumptions can be represented in an equivalent linear programming formulation. However, the number of linear programming columns may be prohibitively large. The point is the simulation/linear-programming approach described above can be thought of as an attempt to create a sample representation of the true dynamic problem. One also must question the effort that should be applied to dynamics that are hypothesized for distant time periods.

The static assumption of linear programming gives the appearance that it is an open loop system (Casti et al. 1983, Jameson and Bartlett 1986). However, FORPLAN models will be updated, at a minimum, each planning cycle and solved anew, thereby incorporating some level of feedback. Solutions from existing FORPLAN models will not necessarily be followed for 50 to 150 years, rather they will be modified and improved as new information is developed.

Vegetative Structure.

A characteristic of all vegetative communities, that is particularly evident in forests, is vertical layering of the canopy and understory structure. There is great variation in the importance of the understory or overstory in different forest types. In many instances, however, the different canopy layers can have important consequences in terms of forest production and wildlife habitat. Although both Version 1 and 2 make provisions for handling two storied stands, Version 1's capability is oriented toward timber. In Version 2, the age of two storied stands created in the model will be tracked and hence wildlife and other relationships can be represented if they can be defined in terms of either overstory or understory age. Multiple storied stands could also be represented using the multiproduct capability of Version 2 but again this would add to the complexity and cost of the model, not to mention the way it would test the user's creativity and gumption. The vertical layering in forest canopies is challenging to model satisfactorily using FORPLAN. Whether this kind of detail is critical to the forest planning analysis depends on the questions being addressed.

Delineation of Land Units for Analysis.

One of the fundamental building blocks of any ecological model is the definition of units of land to be used in the analysis. In FORPLAN the units of land for which management choices (prescriptions) are considered in the linear programming algorithm are called analysis areas. Analysis areas are a requirement in FORPLAN models and every National Forest has defined them. Land is delineated or stratified into units based on the interaction of several ecological components, such as soils, relief, climate, and vegetation. The implicit assumption is that the derived units reflect differences in potential response to management and resource productivity. Surprisingly, there is large variation in the way the analysis areas have been defined from forest to forest. One argument for this is that the planning problems being addressed change from forest to forest. Definition of land units also relates to the spatial content of the analysis and ecosystem under consideration. Therefore, changes in the importance and nature of spatial arrangements from forest to forest can result in different approaches to land stratification. The definition of analysis areas is important in that the yield coefficients for representing production and other interrelationships are developed based upon the assumptions of the underlying units of land (Bailey 1984). This is the first point where incipient variation and error can be introduced into the model by land delineation decisions that are made. It also has a strong bearing on the adequacy of the model for representing ecological processes. For example, if analysis areas are homogeneous units scattered over the entire forest, it may provide for accurate timber volume estimates, but it would be impossible to accurately portray habitat capability for wildlife species that need different kinds of stands within their seasonal home ranges for feeding and cover.

Although some models have been constructed which sacrificed precise homogeneity to increase the spatial content of the analysis areas (which often results in fewer analysis areas), the models have been criticized for being unable to prove that consideration was given to a sufficient range of timber harvest timing choices (management regimes). It would be helpful if the minimum set of timber timing choices that would be necessary to provide a "wide range" could be identified outside of the forest-wide model and be subsequently built into a set of prescriptions which could be applied to larger spatially oriented analysis areas. (See Mitchell (1986) for an approach for selecting relevant timber management regimes).

SUMMARY OF THE ECOLOGICAL EVALUATION

The foregoing discussion emphasizes the fact that ecological modeling for multiple-use in forest planning is much more complex than the single stand analyses that are reported in much of the scientific literature. It involves representing not only multiple stands, but also multiple ecosystems. One might argue that the Forest Service should not be trying to do such comprehensive planning forest-wide, and yet the National Forest Management Act states that a single plan must be produced.

Attempting to represent all the complexity of ecological systems can be overwhelming on the scale of forest planning. The forest planning analysis tool must be able to handle not only ecological, but economic and production aspects of a forest as well. It must not only be able to represent forest dynamics, but also help allocate lands for multiple-use goals. It is, therefore, a meeting place for the results of preprocessors for such things as timber volume tables, demand estimates for developed recreation and the habitat requirements to sustain viable populations of indicator species. On the output side of the analysis, vegetation structure, rates of harvest, estimated road construction, etc. can be used to drive models which simulate the effects on ecological processes which are too complex to include in the FORPLAN model. However, this approach is less satisfying than running more detailed models before the forest-wide analysis and then using their outputs as proxies for the detailed interactions. Any model chosen must be capable of filling this role and handling large implementations.

IMPROVING THE ECOLOGICAL CONTENT OF THE FORPLAN SYSTEM

The National Forest Management Act has put an interesting and demanding challenge to the planner and the ecologist. The most fruitful approach for injecting additional or increased ecological richness into the FORPLAN Version 2 system would appear to be in the pre-processing of input into the model along with post-processing of solutions produced by the model. Adding this level of detail to the FORPLAN matrix generator and report writer would probably make FORPLAN overly complex. Furthermore, ecological sciences do not have a tradition of using linear programming to any great degree when compared with the well-developed traditions of statistical applications and differential equation models. Therefore, we will examine how some of these approaches could be used to improve the results obtained from FORPLAN.

It will be important to keep in mind a critical distinction between two analytical needs during the following discussion. First, there is a need to provide analytical tools which help resource managers understand and predict ecological responses in managed and unmanaged conditions. An array of ecological tools are available to meet this need and they will be discussed below. Generally, these tools are classified as simulation models. The tools in this class are typically not used to simulate an entire forest at once. Second, there is a need to help managers choose the best management alternative to achieve multiple-use objectives based in part on ecological effects. Simulation models can be instrumental in predicting ecological effects at a sophisticated level; however, the second need cannot be met at the forest-wide level if too much detail is carried into the analysis and decision making process. But, the results from simulation models can be abstracted and macro parameters or relationships can be used in an optimization model to help select the "best" alternative. Figure 2 illustrates the concept of using simulators with forest data to provide input into FORPLAN.

The objective is to provide information which allows the exploration of resource production potentials using ecologically sound management. Attempts have been made to accomplish these objectives by creating decision variables for the LP model which are designed for independent, homogeneous analysis areas and using constraints to achieve spatial feasibility. An alternative approach can also be used when one realizes that activities in a geographic area are not independent either in terms of the activities themselves or the consequences of the activities. Decision variables developed based on this philosophy include an implicit land allocation objective and a resource activity schedule besides the environmental effects. The activity schedule is designed spatially and temporally to meet the management objectives implied by the prescription and to comply with the attendant standards and guidelines for such things as maximum opening size and wildlife habitat dispersion requirements. This general approach, whether it is purely area based or a mixed area based, strata based approach will be termed coordinated scheduling to simplify the remainder of the discussion (Iverson and Alston 1986).

Several ecological research areas seem to lend themselves to consideration in this regard. In this final section we will discuss some possible considerations that could improve the FORPLAN Version 2 system in its capability as an ecosystem analysis tool used for the maintenance of the diversity of species (which we earlier identified as one of the principal ecological foci in the National Forest Management Act). The approach proposed also can be generalized to include other resources such as water, range and timber.

HABITAT MANAGEMENT: CONCEPT DEVELOPMENT AND EXAMPLE CASES FROM THE USDA FOREST SERVICE

Continued presence of suitable habitat for the species over time is an ecological analog to the problem of managing a forest for a sustained yield of forest products. Habitat is defined as the kind of place(s) where individuals of a plant or animal species can survive, grow and reproduce. A species' habitat is often quantified in terms of the ranges of physical and biotic factors associated with the presence of individuals of the species. For many animals and particularly for vertebrates (Morse 1968, Shugart and Patten 1971, Dueser and Shugart 1979, Franzreb 1983) the structure of the vegetation is a major element in determining the suitability of the habitat (Hilden 1965). Because the vegetation can be altered by both natural (succession, disturbances) and human-controlled processes (timber harvest), the ability to project vegetation change over time is an essential element both of managing certain species' habitat for productivity and recreational uses on a continuing basis and of minimizing the potential extinction of certain other species.

During the early 1970s the USDA Forest Service was a leader in working with the problem of managing public lands to insure the maintenance of diversity. The agency sponsored open symposia (e.g. Smith 1975, Capen 1981) on scientific problems and applications and helped to catalyze an innovative period for scientists interested in exploring habitat management techniques. Two different management approaches were developed under direct influence of the economic and political constraints attendant to the land management problems in their respective regions of the United States. These two concepts were the "featured-species plan" (Zeedyck and Hazel 1974) used in the productive forests of the southeastern United States and the "area-diversity plan" (Evans 1974) used in the hardwood forests of Missouri.

In the featured-species plan (Zeedyck and Hazel 1974), species of birds or other animals (usually traditional game animals) were studied to better understand their ecological requirements and to develop a plan for forest management. The resulting plan would optimize the availability of habitat for the featured species considering other resource values in the area.

In contrast, the area-diversity concept (Evans 1974) was designed to create an optimal diversity of animals by managing land to insure the presence over time of all the recognizable habitat types in a region. The plan evolved in Missouri in a hardwood forest region in which all but the most productive forests were used for recreation and watershed protection. The area-diversity plan uses ecological diversity as a central principle and uses the treatment of blocks of land (ca. 40 ha) to maintain a landscape mosaic of different habitat types. Tracts of land are cut and even-aged forests are regenerated on the cut-over sites. The amount of land cleared in any given year is designed to initiate a sequence of tree regeneration and regrowth leading to mature forest. Such a system is very conservative in terms of how much land might be harvested in a given year.

These approaches to developing management plans, and others (Gill et al. 1974, Holbrook 1974), have evolved considerably since the early 1970's. For example, a management plan that was an area-diversity plan might use a featured-species plan on areas that harbored a rare and endangered species or an important game species (Zeedyck and Evans 1975, Harris et al. 1984). The Forest Service now uses as a matter of policy a synthesized version of the two approaches called management indicator species (Mealey

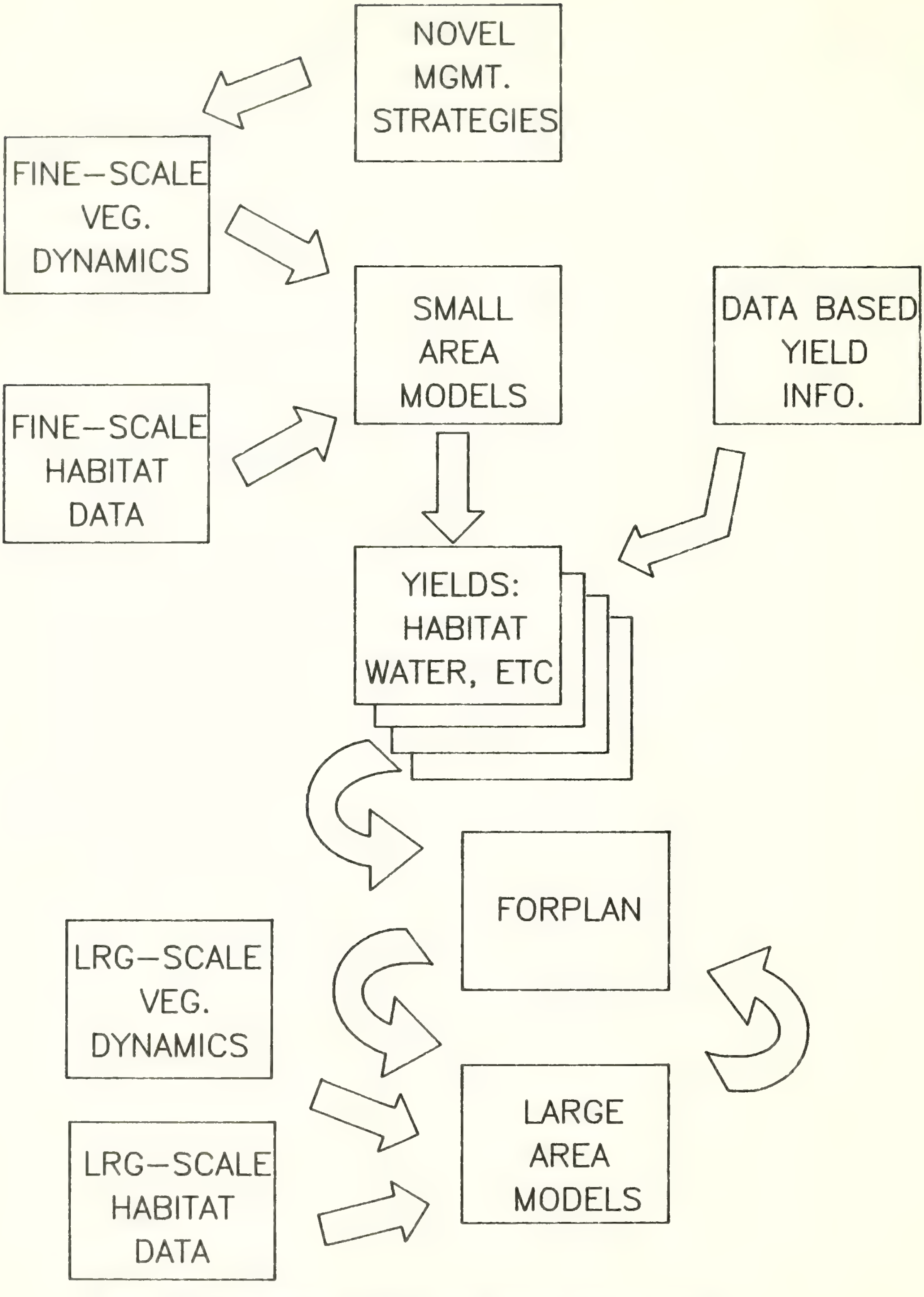


Figure 2.--Example information flows for large- and small-scale simulation as post- and preprocessors to FORPLAN. Large-scale models also could be used as preprocessors if appropriate.

and Horn 1981, Salwasser and Tappeiner 1981). Key elements of both of the approaches include the association of plant or animal species of interest with habitat and the understanding of the dynamics of habitat (and the consequent need for an active and sustained management plan). These elements can be augmented technologically using computer models to simulate the dynamics of the vegetation and using more accurate descriptions of habitat resulting from the application of modern statistical techniques. The most important aspect of these habitat management plans is that they form a background in experience and concept for a landscape/ecosystem management scheme that can be used to manage large areas to conserve diversity.

ECOSYSTEM/LANDSCAPE MANAGEMENT

The featured-species and area-diversity concepts have an important difference in scale: The featured species concept is a fine-scale technique that allows one to tailor a tract of land for the apparent needs of particular species. The area-diversity concept is a larger-scale technique that is more oriented to maintaining regional-scale diversity. There are three key elements involved in developing an ecosystem/landscape management plan for regional species diversity:

1. The ability to associate individual species with the features that make up a landscape.
2. The ability to predict the changes in the character of the landscape.
3. An understanding of the way species will respond to a dynamically changing landscape. This understanding should be both species-centered (how the dynamics of the ecosystem might effect a particular species of interest) and ecosystem-centered (how the success or failure of a given species might effect other components of the ecosystem).

Key Element 1: Associating Species with Landscape Features.

Models that relate organisms to habitats or other features of the landscapes form a diverse array of methodological approaches and a correspondingly large scientific literature. The more recent cases are dominated by statistical approaches. These cases differ most clearly in the scale in space to which the methods can be expected to apply. A dichotomy of large- (usually greater than 100 ha) and small- (usually smaller than 1 ha) scale methods can be used to frame a general discussion.

Large-Scale Approaches

For animals, there is a large repository of information that associates the abundance (or potential abundance) of a species with the condition of a large tract of land. In general, one uses a high density of a given species as strong evidence for the suitability of a given sort of habitat. This may not always be the case. For example, Van Horne (1983) proposed that habitat quality be defined in terms of fitness (an index that increases with the probability that a given individual organism will produce viable offspring) and noted several cases in which high densities in a given habitat did not necessarily show a high fitness. One such case occurs when large numbers of subdominant individuals are forced into marginal habitats by more dominant individuals during episodes of high population densities. In such instances the densities in what is marginal habitat can be misleadingly high. Such cases have been documented for small mammals (Kock et al. 1969, States 1976, Schantz 1981) and birds (Fretwell 1969, O'Connor 1981). These considerations speak to a need for more insight into dynamics of the populations as an aid to better management.

Methodologies that use presence or abundance of a species to determine habitat quality and then use such information in habitat management generally are based on correlations. Thus, a species which occurs in a habitat called "hardwood forest" provides a reasonable expectation that it might occur in a managed hardwood forest; but this expectation is based on the strength of correlations between the apparent animal abundance and the features of the gross habitat over large tracts of land.

The problems that are potentially associated with the use of correlational relationships to design management schemes to insure a maintenance of diversity sound a cautionary note and underline the need for continued studies to improve management plans. The minimal level of follow-up studies would be the continued monitoring of the managed system to determine if the management plan was producing the desired results.

Small-Scale Approaches

An alternative method of associating a species with habitat is to correlate the presence or abundance of the animal or plant with habitat features measured at a very fine spatial scale (typically 0.1 ha or less). The essential observation behind these small-scale approaches is that a species found in, say, "Oak-Hickory Forest" is not necessarily found in all parts of such a forest. The habitat of the species is characterized by the unique features of the subset of the area where individuals of the species are most often found. There is an element of capitalizing on the heterogeneity of pattern in habitat to understand in greater detail the factors controlling the distribution of a species.

These approaches explore the correlations among the species occurrence and the quantitative measures of the habitat (Capen 1981). The statistical methodologies used are often based on multivariate models that can take into account the intercorrelations that are a prominent feature of sets of habitat variables (Green 1980). Unfortunately, these methods also tend to render the results of such analyses to a form that is not easily understood by most land managers.

Key Element 2: Predicting Changes in the Character of the Landscape

Large-Scale Approaches

There are two sorts of simulators that are logically compatible with a landscape mosaic concept of ecosystem dynamics. According to this concept the expected change in a landscape over time is obtained by summing the response of many patches as simulated by such models.

Vegetation/patch simulators project the change in landscapes at the scale of hundreds of hectares and sometimes hundreds of square kilometers. The models tend to be mathematically simple compared with the individual-plant simulators that are discussed below. Markov models of landscapes are a typical example. Markov models are based upon certain assumptions in their application at the landscape level:

1. They are based on the assumption that a landscape can be divided into a set of discrete patches.
2. Change in the vegetation is expressed as a set of probabilities that the vegetation will be in some other state at some fixed time later, given the state of the vegetation on a patch at the present (transition probabilities).
3. The probabilities of change are assumed to be constant over space and time.

It is a definite advantage of the Markov formulation that the parameters are straight-forward in terms of what they represent. For example, see the work of Kessell and his colleagues who developed several models for use in landscape management of national parks in the United States, Canada, and Australia (Kessell and Potter 1980, Kessell et al. 1982). One can use remeasured vegetation survey data to obtain the transition probabilities (although it requires a considerable amount of such data to estimate the parameters of a Markov model that has very many states). In several cases, the parameters of Markov models have been estimated by inference. For example, Horn (1975) assumes that the percentage of young trees growing beneath large canopy trees of a given species could be taken as an estimate of the transition probability in a Markov model. Waggoner and Stephens (1970) provide an example of using resurvey to parameterize a Markov model for a forest in Connecticut. The current modifications in the FORPLAN Version 2 model that involve probabilistic outcomes (Johnson and Stuart 1984) could make the incorporation of Markov succession models into FORPLAN feasible.

Small-Scale Approaches

Individual-plant vegetation simulators in current usage today also often are developed with the view that the landscape can be considered to be a mosaic of patches where each patch can be thought of as having some description about the type of vegetative cover. Unlike Markov models, these small-scale models are constructed to simulate with some degree of detail the ecological interactions within each patch. Often, the models compute the dynamics of individual plants within each simulated patch and produce predictions that are quite detailed. As an example of a small-scale vegetation simulator, one might consider gap models of forest dynamics (Shugart 1984).

Gap models function by computing the diameter increase of each of the trees growing on a small simulated plot around 0.1 hectares. The trees are increased in size annually. Mortality of the trees on the plot and the birth of trees are stochastic functions that are also applied annually. The fundamental approach in developing these models was outlined by Botkin et al. (1972). Shugart (1984) provides a detailed explanation of the model assumptions and relates the behavior of several gap models to modern ecological concepts of forest dynamics. The models do not require elaborate data sets for parameter estimation. The philosophy that underlies the development of gap models is to represent the dynamics of the forest using general equations that can be obtained from basic physiology, morphology and silvics of trees. The models have been successfully tested against independent data in several cases and appear to do a reasonable job of predicting the pattern and dynamic change in forests.

Another example, which is interesting from the standpoint that an ecological objective was being sought, is provided by Rice et al. (1985). The model was developed as part of a project with the objective of achieving a higher species diversity on dredge spoils in the Colorado River than any naturally occurring riparian vegetation in Arizona. The objective was achieved and the model was used to assess changes in presence and abundance of about 70 species to changes in management.

Both the large- and small-scale models have certain advantages and disadvantages in terms of their application to landscape management problems. In the example model types above, the gap models run more slowly on a computer and require a research scientist with some training in ecological modeling in their development stage. Gap models can be used to produce a detailed description on each of the plots that sample a landscape and often have a sufficient degree of realism that they can be used to predict the response of a landscape to a novel change (e.g. climatic change, air pollution stress, change in wildfire regime). Markov models are computationally fast and easily set up on most computers. They can be used to generate dynamically changing maps. Markov models require a considerable amount of data for parameter estimation, particularly in complex systems and they have no internal mechanisms in their formulation that would allow them to be expected reasonably to predict system response under novel conditions.

The most logical evaluation of the question, "Which model should be used to estimate yields for FORPLAN?" is to say, "Both." The two modeling approaches are compatible and a wise approach to using the models to predict landscape change would be to develop a nested set of models with the gap models being used under novel conditions and the Markov models being used for the large scale projection of landscape change. The gap model output is more compatible with the scales used in multivariate statistical studies of animal habitat selection; the Markov approach leads one to attach more general habitat descriptions of the sort used in field guides to suggest where a species might be found.

Key Element 3: Organism and Landscape Interactions.

The venerable concept in ecology, that landscapes can be viewed as dynamically changing patches, (Aubreville 1933 and 1938, Watt 1925 and 1947, Whittaker 1953) has recently emerged as a strong unifying concept in forest ecology (Bormann and Likens 1979a, 1979b; Whitmore 1982; Shugart 1984). Bormann and Likens (1979a) noted that forest ecosystems "... may be visualized as an array of irregular patches composed of vegetation of different ages. The structure of the ecosystem would range from openings to all degrees of stratification, with dead trees concentrated on the forest floor in areas of recent disturbance. The forest stand would be considered all-aged and would contain a representation of all species, including some early successional species, on a continuing basis." Watts' (1947) classic paper documents this same concept for a wide range of ecological systems including not only forests but bogs, heathlands, grasslands and alpine communities.

The use of multivariate statistics to quantify the relation between organisms and habitats fits naturally with the mosaic concept of a landscape. This is a consequence of research scientists designing multivariate techniques which attempt to capitalize on the fine scale heterogeneity of the landscape to provide insight into patterns of habitat selection. For this reason, the samples used to provide the basic data for the multivariate analysis often are collected with the explicit goal of having spatial dimensions that are analogous to those of the pattern of the spatial mosaic and thus match the scale of the elements of the landscape mosaic.

If the scale of a landscape simulation model and the scale of the data used to calibrate a species/habitat relationship are compatible, then one can meld the two to simulate the dynamics of populations in response to a dynamically changing landscape. Table 1 summarizes the relationships of large and small scale modeling tools to the three key elements involved in developing ecosystem/landscape management plans for species diversity.

There are potential errors in using such an approach that could stem from several sources. Errors estimating the nature of the association between the habitat and the species presumably can be minimized by increased sampling. Errors resulting from the inability of a landscape model to exactly reproduce the conditions on the modeled landscape is another primary source of error that can probably be minimized by a rigorous model-testing/model-reformulation protocol. A third important source of errors could arise from important interactions not included in the model. These errors could be because of spatial effects not included in the model (dispersion of a species across a landscape might be so slow that it prevents the colonization of newly generated habitat before it disappeared because of successional processes.) Another source of the errors outside the model formulation could be interactions with other species that are also using the landscape (competition, predation, parasites harbored in one species infecting another species). Control of these sources of error require a concerted effort in basic ecology particularly focused on environment/organism and organism/organism interactions.

THE RELATIONSHIP OF ECOSYSTEM/LANDSCAPE MANAGEMENT TO FORPLAN

FORPLAN models used for forest planning typically depict vegetation dynamics at a large scale, while spatial interactions may or may not be handled depending on the model. Before constructing a FORPLAN model, the relationship of indicator species to habitat is determined outside of FORPLAN and then the relationships are incorporated into the model to the extent possible. Solutions from FORPLAN show how habitat, or indicators of habitat, change through time. Habitat changes may be a consequence of vegetative treatment for other resource benefits or result from direct habitat improvement projects. Models of the type described above (mosaic/patch simulators) can be used to help predict the consequences of such management activities on wildlife habitat including some of the spatial effects. For example, under novel conditions, such as innovative management techniques, the small scale models can be used to estimate yields and effects. Similarly for areas where empirical data is weak or missing, results from such models can be used as proxies for actual data. However, large scale models can be used when circumstances are better understood. Model results can in turn be input into FORPLAN and can be used as part of the criteria for determining the optimal solution for a particular plan alternative. Under this scenario the input would be in the form of integrated production functions, i.e., yield tables, for management prescriptions (See Mealey et al. 1982 and Stage et al. 1986 for examples of how this might be accomplished in the forest planning context, fig. 2).

Approaches to resource integration such as this parallel what is happening on many national forests during plan implementation, although computer models are not always used (Sweeney 1985, Holthausen and Dobbs 1985, Benson and Landenslayer 1985). The difference in what is being described here is that the integration and some of the spatial analysis is done before choices being entered into the LP model (called coordinated schedules). Several forests have tried this approach on all or part of their land base. Although this approach requires more work before running FORPLAN, there are several advantages, some of which address the philosophical criticisms presented at the beginning of this paper. It is important to realize that some of the advantages such as reduced FORPLAN model complexity are achieved at the expense of increased analysis before FORPLAN.

The criticisms related to model size can be resolved, because far fewer columns are needed to represent timber timing choices. Presumably, all the analysis done during this round of planning will provide insights into logical timber

Table 1.--The relationship of large and small scale modeling tools to the three key elements involved in developing ecosystem/landscape management plans for species diversity.

Key elements	**Large-scale**	**Small-scale**
Associate species with landscape	Correlations based on presence or abundance with monitoring to help verify correlations	Multivariate Statistical models with intercorrelations
Predict changes in the character of the landscape	Markov models with constant probabilities	Mechanistic ecological interaction models (e.g. GAP models)
Predict interactions of the species with its landscape	IF the scale of the species habitat relations are the same as the simulation model, THEN the dynamic changes of population as a function of changing landscape can be simulated.	

management regimes for the next round of planning. In addition, the coordination of harvests within an area is likely to reduce the need for so many timing combinations. Furthermore, fewer constraints are required to achieve spatial feasibility, because spatial feasibility is determined for prescriptions before they are included in the model.

Johnson (1983) captured the essence of the major problem with coordinated schedules:

> "The reduction in model size gives some clue about a disadvantage in representing scheduling choices on an area basis. These choices are time-consuming to construct and require considerable imagination. Probably not all of those that might be developed will be represented in the problem. Therefore, achievement of the objective specified for the problem may be reduced not only because of the constraints implied by the standards that must be met, but also because important choices were left out."

Furthermore, there is a need for the decision variables to be selected in their entirety in the optimal solution. LP algorithms will not necessarily satisfy this need and therefore special techniques may be needed to obtain sensible solutions (Johnson et. al 1986). Finally, in the analytic framework used by the Forest Service, where economic tradeoff analysis is stressed, it is difficult to show the cost of constraints that are integrated into decision variables.

Forests that have been successful with coordinated scheduling have used it only on portions of their forest and for the early part of the planning horizon where they have a good notion of a reasonable range of choices. Such a compromise approach has two advantages, one being less work for the ID Team in creating the schedules, and the other making realistic solutions easier to obtain using LP. LP solutions are more easily obtained because acres for which coordinated schedules are not used have more scheduling flexibility which allows constraints such as nondeclining yield to be more easily satisfied. Furthermore, if schedules are coordinated for only the first part of the planning horizon additional scheduling flexibility is permitted later in the planning horizon. A compromise coordinated scheduling approach fits well with the intent of forest planning, which is to "evaluate immediate decisions with an assessment of the long term consequences" (Barber 1986).

Models formulated this way are simpler and less expensive to solve, therefore, more analysis can be done. Solutions are easier to check for reasonableness and to disaggregate to the ground because integrated, implementable prescriptions are entered into the model. Perhaps the biggest payoff, however, is the enhanced ability to comprehend and explain the solutions to management and the public. The ability to see the selected schedule for an area would greatly enhance this understanding. Finally, the ability to better understand the results will lead to them being used by decision makers and managers, the final goal of modeling and analysis.

SUMMARY AND CONCLUSIONS

Such a revised approach to formulating FORPLAN models has potential to improve the analytic results and their utility. Using a combination of simulation pre- and post-processors with an LP land allocation and activity scheduling model allows the analyst to use the strengths of both tools to address all the necessary ecological facets, while minimizing the weaknesses of each modeling approach. However, this alone will not suffice. It is also necessary for ecologists and scientists working with resource managers to explain the significant production functions necessary to make management decisions. NFMA states in Sec. 6 (g)(3)"(c) insure research on and (based on continual monitoring and assessment in the field) evaluation of the effects of each management system to the end that it will not produce substantial and permanent impairment of the productivity of the land." This statement provides the impetus for examining ways to efficiently determine and modify production functions using new systematic approaches to monitoring (Walters and Hilborn 1978, Sisler and Jameson 1983, Holling 1978). The challenge is to capitalize on the continuing management experiments being conducted by the Forest Service such that better management decisions can be made in the future.

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A Discussant's View of an Ecological Evaluation of FORPLAN

Linda A. Joyce[1]

Abstract.--An ecological evaluation of FORPLAN involves an evaluation of FORPLAN against the modeling objectives described in the National Forest Management Act, and an evaluation of the ability of FORPLAN and the actual forest models to portray the ecosystem behavior of concern in NFMA. Improvement of the modeling process within land management planning must include a consideration of the scale of the planning problem, modeling approaches appropriate to the scale, and the feasibility of implementing the modeling approach in land management planning.

The critique of FORPLAN from an ecological perspective is a difficult task, and Shugart and Gilbert (1987) have presented an excellent paper towards that goal. The purpose of this paper is to discuss further these issues:

1. the basis of an ecological evaluation of FORPLAN;
2. the technical considerations using FORPLAN to model ecosystem dynamics;
3. reflections on improving FORPLAN.

The Basis of an Ecological Evaluation of FORPLAN

Objectives of the Analytical Tools

An evaluation of FORPLAN from an ecological perspective presumably would take the set of objectives which spawned the development of the modeling system of FORPLAN, the array of actual models constructed using FORPLAN, and evaluate the ability of these systems to portray the ecosystem behavior of concern in the objectives. Uncovering the specific objectives which prompted FORPLAN's development leads to the National Forest Management Act (NFMA). When the Act is used to determine the objectives for the analytical techniques, one must conclude that the Act is vague. Woven throughout Shugart and Gilbert's (1987) paper is a persistent struggle about just what the true objectives of the analytical tools directed by NFMA were.

The law was written when no one knew precisely what forest planning would encompass. Diversity was understood to represent stability at the time the act was written. Over time, our interpretation of words in the act, our understanding of Forest Service land management planning, and our understanding of ecological theory have changed. Different words in the law were **key words** and become **key words**. Today, more factors than diversity have been identified as contributing to stability in ecosystems, for example. A current evaluation of the initially chosen analytical techniques will be based on this evolving perspective of land management planning and scientific theory.

As outlined by Shugart and Gilbert (1987), the Act implies that the analytical tools must be able to:

1. Consider sustained yield of all multiple uses,
2. Coordinate all resource management,
3. Evaluate alternative management systems with economic and environmental effects, and
4. Address the diversity issue, although no model was specified in the Act.

Specifically, NFMA requires that the **forest plan** must show that these factors have been weighed reasonably in the management decision. This "reasonableness" will be defined, most likely, in terms of a "record," which will prove to a judge, that all the relevant factors have been weighed by the decision maker (Fairfax 1980). To quote Fairfax, "Judgment based on the wisdom of experience is not legally reasonable." Shugart and Gilbert assume in their critique that the forest plan must show this reasonableness by quantifying the entire management selection process.

The authors portrayed large model development occurring in situations where there was no intuitive solution. I suspect that forest managers have the intuition to manage wisely. To propose any other answer would suggest that the Forest Service promoted poor managers or that the Forests were in trouble long before NFMA. What appears to be happening is that we are trying to quantify that intuitive answer to prove its adequacy to others. When the number of groups participating in the planning process increases, the number and diversity of intuitive explanations increases also. For example, Shugart and Gilbert point out two management styles: proactive and reactive.

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Models developed to examine ecosystem dynamics versus obtaining consensus on opposing environmental views have been very different in practice. The former have been highly detailed complicated models, such as the IBP Biome ecosystem models (Innis 1978). The latter have been largely intuitive models where the computer was used to quantify and condense those differing perspectives on environmental management, such as the Adaptive Environmental Assessment models (Hollings 1978). Shugart and Gilbert conclude that the analytical tools needed to support the NFMA fall within the category of models examining ecosystem dynamics. By the end of their paper, their struggle with objectives is resolved in development of two analytical needs that must be met in any improvement of the FORPLAN system. The analytical tools must be able:

1. to help the resource manager understand and predict ecological responses to managed and unmanaged conditions;
2. to help managers choose the best management alternative to achieve multiple use objectives based in part on ecological effects.

Ecosystem Behavior

If we take these objectives as the starting point to critique FORPLAN, two questions arise about ecosystem behavior:

> Must the resource manager, or the analyst, understand and predict **all** ecological responses to managed and unmanaged conditions?
>
> What ecological effects must be quantified in order to choose the best management alternative to achieve multiple use objectives?

When NFMA was written, diversity was a key ecological idea that was used to ensure the stability of the ecosystems on national forests. Shugart and Gilbert cast up what has become important in modeling forest dynamics using FORPLAN. Presumably, if FORPLAN or the forest models were able to simulate these facets of ecology, then one could conclude that FORPLAN/the actual forest models were appropriate tools to model ecosystem behavior. FORPLAN is different from the actual forest models. A tremendous responsibility rests with the analyst in the development of the actual structure of the forest model. If FORPLAN can handle any of the above ecological facets, it is not guaranteed that the actual forest models modeled the ecological facet. This difference is critical. If one forest found a way to model these ecological facets using FORPLAN, then FORPLAN can be used.

If we look at the author's conclusions, FORPLAN, under a set of assumptions, can handle these ecological facets, as shown in table 1. A yes implies a suite of assumptions, not the least is model size is unconstrained, or the number of timber alternatives is reduced from all possible, etc.

Table 1.--FORPLAN's ability to model the ecological facets.[1]

FACET	Ability
Nonlinearities	YES
Time Scales	YES
Multiresource Interactions	YES
Spatial	YES/NO
Variations and Model Error	NO
Uncertainty	NO
Succession	YES
Dynamic Ecological Processes	MAYBE
Vertical Diversity	YES
Land stratification	YES

[1] Given many assumptions such as model size is unconstrained or timber alternatives are reduced.

Technical Considerations When Modeling Ecosystems Using FORPLAN

Nonlinearities

The ability to describe non-linearities in ecological relationships is the well-worn criticism of the application of linear programming to ecosystems. These problems have been discussed by others in these proceedings. It is probably safe to conclude that LP models can represent nonlinear responses under certain circumstances: when the output response increases as management intensity increases on a per acre basis; when the output response changes as the number of acres change.

An additional problem occurs in the building of the actual model using the structure of LP, not in the structure of the LP model itself. Non-linear functions of management activities are difficult to convert into approximate linear relationships. The model builder's perception of the environmental system will affect the scale of the forest model. The scale of the forest model will affect the ecological processes critical to be modeled. Some of these processes will be nonlinear. Shugart and Gilbert acknowledge that LP structures are not common in ecological modeling. Thus, little guidance is available to offer the model builder ways to incorporate nonlinearities into the LP structure.

As others have noted, there is an additional problem associated with nonlinearities in ecosystems--spatial patterns affecting the production response. The significance of this spatial patterning is a function of the scale of the model (Milne 1987). Scale also enters into the discussion of the LP models ability to model the resource response to catastrophes. For example, on any scale, the ecological responses to road building can be described as a catastrophe. This is not to suggest that technology can fix everything or that catastrophes do not occur in ecosystems.

Nonlinearities in ecosystem processes are a function of the scale at which they are examined. The model builder's perception will affect the level of scale to be modeled, and, therefore, the amount and difficulty of nonlinearities that must be modeled.

Multiresource Interactions

Linear programming models are the intersection point for economic values and ecological production in quantifying the management decision process, and multiresource interactions. From a theoretical perspective, the use of LP models can be justified on the basis that the LP model traces out an approximation of the production function of the forest. Choices between resource management practices can be made considering production spaces, and the production frontier.

Shugart and Gilbert state that, "It is not at all clear that the management strategy for optimizing money developed by using a FORPLAN model, under a constraint of maintaining a given level of animal species diversity, would even resemble the optimal strategy for optimizing diversity under the constraint of producing a certain cash flow." In theory, if the cash flow constraints were defined similar to the money functions optimized, the resource outputs would be the same for both LPs. The total number of management prescriptions in the LP approximates the production space of the system. If the number of management prescriptions is fewer than the total number feasible, then the LP will poorly approximate the production space of the forest. One must ask would the management prescriptions be different under the two scenarios the authors proposed because of omissions of necessary prescriptions from the model structure? Does optimization of species diversity conjure up a different perception of the necessary management prescriptions than if the forest were managed to optimize cash flow? If yes, then the problem is in the model formulation, because the incorporation of management prescriptions has been biased by a singleness of the goal and the production space has only partially been described in the LP.

Although ecologists agree that the input of labor and capital change the function and structure of the ecosystem, ecosystem simulation models rarely have quantified the impact of management and the mitigation necessary to respond to a change in the structure or function of ecosystems. Ecosystem models often describe the system dynamics under management, such as harvesting, or clearcutting. But, rarely, is the model used to determine the type of management action necessary to mitigate the undesirable aspect of the management action. We must ask the question, "What is the role of ecological simulation in describing the production space of the resource system?" Is the idea of a production space or the production frontier fully understood by the resource specialists/ecologists when the actual forest model is constructed?

Little ecological theory has been incorporated in the development of the economic joint production theory. The assumptions underlying the theory have not been tested using ecological theory. Economists assume that an ecosystem functions in a manner similar to a firm. The underlying structure of a firm is known with certainty, but the underlying structure of ecosystems is not known with certainty. Further work is needed here to examine the implications of these assumptions.

Spatial and Temporal Scale

The spatial and temporal dimension of ecological relationships is a difficult concept to incorporate into the actual forest models. This dimension becomes especially important when the management action disrupts a rhythm of resource production which assumed a certain spatial or temporal distribution, previously unrecognized.

The most obvious representation of the spatial dimension is the analysis area. As the authors point out, analysis areas are delineated upon the interaction of several ecological components, such as soils, relief, climate and vegetation with the implicit assumption that these derived areas reflect differences in potential response to management and resource productivity. Determining the yield coefficients which represent resource production within these analysis areas significantly affects model adequacy in representing ecological processes.

The spatial and temporal character of the land changes under management and varies by resource. When a function such as mining enters, the historical ecological components may have nothing in common with the future ecology of that site. To resolve these problems, we become "splitters" in land classification rather than "lumpers." This forces the scale to finer and finer levels, and the LP model to larger and larger sizes. This process assumes that a land taxonomy will provide the basis on which the system will function under management.

Once the fine grid of analysis areas is defined, model coefficients are derived to represent resource production on the analysis areas. Model coefficients will have inherent variability, and could be described using inventory measurements. However, this variability maybe significantly different across analysis areas or maybe a function of the land classification. The significance of scale is being recognized as increasingly important (Allen and Starr 1982) and may have a substantial contribution in sorting out this land classification problem.

While the implications of scale in quantifying ecological processes are evolving, scale is also important in economic considerations in FORPLAN. The definition of management prescriptions involves a consideration of what activities ought to be included into the model. The scheduling of harvest involves many activities that are not specifically incorporated into the LP model. These activities are deemed of little importance in the scheduling of timber at the analysis area level or forest level.

Residual Unpredictability

Uncertainty in ecological processes is difficult to incorporate into a static model. Unlikely events occur in ecosystems and these events impact the survival of plant and animal populations. As the authors point out, the difficulty is in realistically representing the consequences of uncertain events. The ecosystem can be seen moving from one equilibrium to another equilibrium. Risk analysis prior to the LP model has been used to reconcile uncertainty in minimum viable populations by determining the constraint necessary to keep the system from moving out of the desired equilibrium (Salwasser et al. 1984). This approach works when the consequences of the uncertain event to be avoided can be described, extinction of a population or species, and the LP model contains the necessary variables which must be constrained, habitat variables. This approach does not work for events, such as floods or pest outbreaks. As Hof (1987) has discussed, the LP framework may not be the appropriate tool to model these events.

Once the FORPLAN model is constructed, all aspects of the structure of system appear to be **known** with certainty. That they are accounted for with certainty is another problem. What is meant here is the uncertainty that cannot be explained, the ignorance of processes that are reflected in the variability and that cannot be linked to a casual explanation. This type of uncertainty, called "residual unpredictability" by Walters and Hilborn (1978), affects the ability of the model to project.

A long line of modelers, including some ecological modelers such as Karplus (1975) and Walters and Hilborn (1978), have long urged acceptance of the uncertainty in ecological systems, or rather, acceptance of our inability to precisely model ecological systems. Walters and Hilborn (1978) described current ecological management as a passively adaptive discipline:

> "We observe disturbed systems, synthesize sometimes elaborate models, and conduct optimization exercises which pretend that our actions will not affect the way we observe and learn in the future. Eventually, with luck, we are able to devise optimal feedback policies. These specify the best behavior in the face of a residual unpredictability whose probability characteristics we have discovered through experience. Along the way we waste a lot of time trying to understand how this residual variability arises, forgetting that we usually cannot do anything about it."

Our understanding of ecological responses and our ability to quantify some of the components of that residual unpredictability have increased over time. To say that we usually can never do anything about that uncertainty might be a strong statement. However, it is equally absurd to conclude that the residual unpredictability does not exist, as we do in models which have a fixed structure.

The model represents the best quantification of the system. The impact of the known variability on this projection estimate must be ascertained to further reduce this component of the projection variability. Dixon and Howitt's (1979) work in California showed possible approaches to model refinement using control theory. It is more difficult to assess the impact of the residual unpredictability of the projection estimate. The LP model structure makes it difficult to incorporate this uncertainty. It is difficult to link the movement of ecosystems from an equilibrium characterized by a continuous smooth surface to a new equilibrium in which the surface is not continuous (Walters 1986). To demand this from a planning model may be too large of a task. To ignore it is impossible. The middle ground may be to devise an approach to incorporate the uncertainty so that it provides information which can be used to redirect the change in the model. Sisler and Jameson's (1983) work on monitoring has shown a feasible approach using control theory.

Improving the Ecological Content of FORPLAN

Shugart and Gilbert (1987) propose an interactive relationship between FORPLAN and Forest Simulators shown in figure 1. This approach has much utility. It addresses the problems of scale, incorporates some measure of uncertainty, and offers the potential of reducing the size of the final forest-level model.

Perhaps, the most important point of this proposed improvement is the recognition of scale in quantifying ecosystem dynamics. What Shugart and Gilbert have proposed is a modeling system tailored to describe ecosystem dynamics at more appropriate levels of scale by appropriate modeling techniques. What will this approach require?

First, it will require that species/habitat relationship models be constructed for selected species (or indicator species, etc). This requires multivariate data linking the species with the habitat. Further, the multivariate data describing the habitat must be of the same type of the data available in the vegetation/patch simulators.

Second, it will require that vegetation/patch simulators be constructed for forest types on a forest. Again, this requires data on forest management and tree dynamics. This requirement may not be too difficult to accomplish for the individual plant vegetation simulators, because these use much of the forest managers' intuitive experience along with available data.

This approach will rely heavily on the choice of patch size. This becomes the indivisible unit, like analysis areas, and all forest dynamics must be described in terms of this size. It also will require inventory data to construct the species/habitat relationship models. Ultimately, a link between the needs of the analytical tools and the inventory would improve models.

Conclusions

Shugart and Gilbert proposed three criticisms of using large models: a distrust arising from model complexity--small is beautiful; the difficulty of comparing intuition and model results; and the computer costs involved in running models. These criticisms can be restated in a broader framework: the role of model abstraction in land management planning. Ecosystem behavior is known only in part, and never with certainty. The ability of the analyst to abstract the environmental system using FORPLAN is crucial to the success of the actual forest model in describing ecosystem behavior.

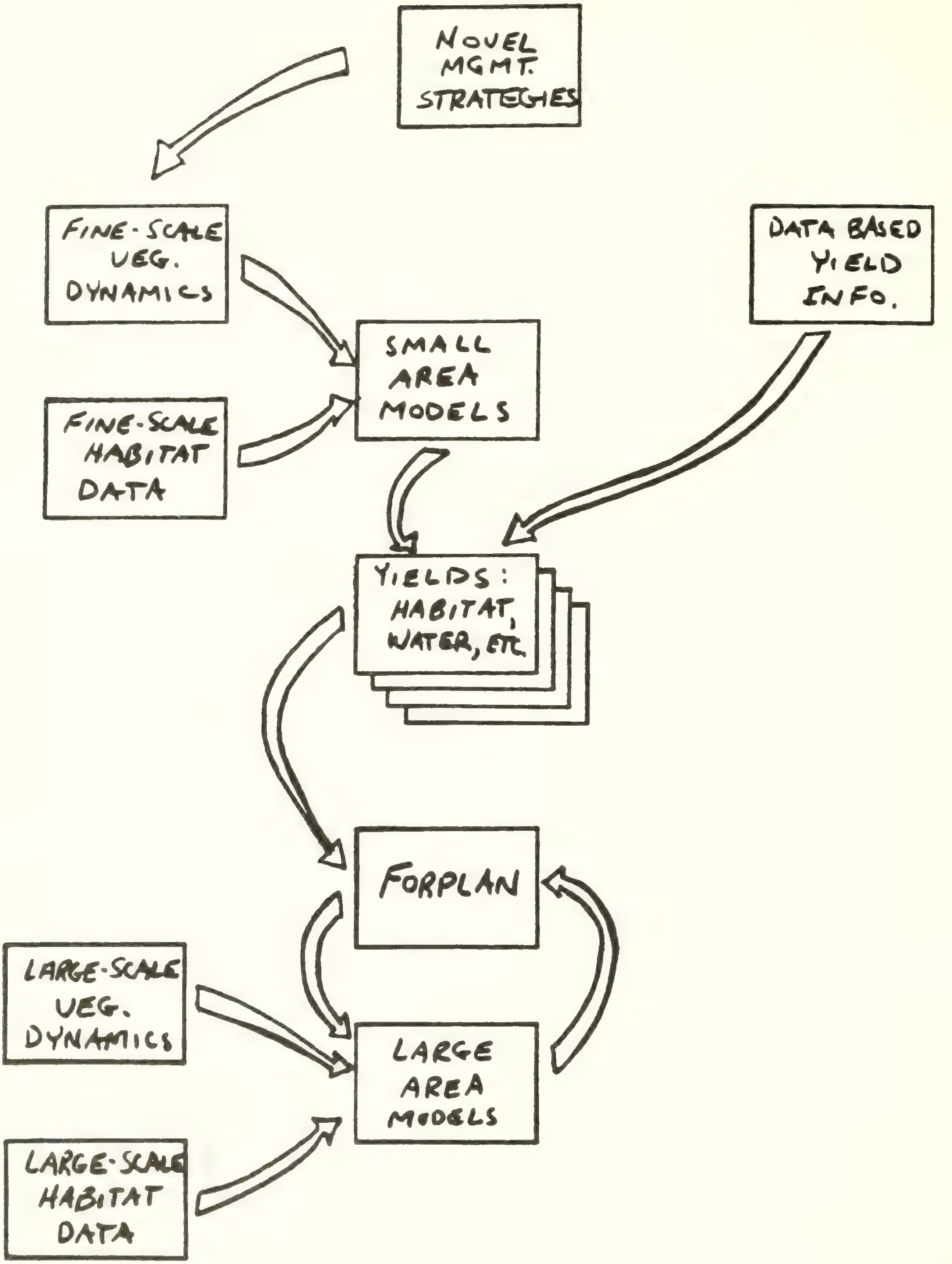

Figure 1.--Proposed improvements in the modeling systems used in land management planning (Shugart and Gilbert 1987).

While I agree with Shugart and Gilbert that the objective of model abstraction in land management planning is to allow the exploration of resource production potentials using ecologically sound management, must this entire process be quantified in the forest modeling system? What aspects of the ecological system must be abstracted in the modeling part of the planning process?

What did NFMA imply about the objective of the analytical tools? Were the models to allow resource managers to reach consensus in the public involvement process, or were resource managers to use the models to gain insights into the production space of the system. What has FORPLAN done? I believe that FORPLAN attempted a difficult goal: to be both types of models.

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Hierarchical Landscape Structure and the Forest Planning Model: Discussant's Comments

Bruce T. Milne[1]

Abstract.--Special strategies are needed for building models sensitive to the hierarchical structure of landscapes. Such hierarchical models may be effective for extrapolating from fine- to broad-scale predictions. In some applications, landscape dynamics may be simulated using enhanced Markov models, especially where the effects of neighboring patches are relevant. Combinations of geographic information systems and Bayesian models of wildlife habitat offer a powerful means of linking FORPLAN results to the ground.

Shugart and Gilbert (this volume) raise many considerations regarding the application of FORPLAN to resource management in the National Forests. Their review covers two general topics: (1) philosophical considerations stemming from the application of large, complex models, and (2) ecological ramifications of the assumptions and algorithms of FORPLAN. These topics are linked by the constraints that a particular paradigm, either philosophical or ecological, impose on the design and implementation of a model.

Here, my comments emphasize the structural aspects of landscapes. First, I comment on the complex hierarchical spatial structure of landscapes, thereby highlighting an alternative paradigm which may prove useful in landscape planning. Second, I suggest several modeling strategies reflecting the hierarchical structure of landscapes. These comments were prompted by Shugart and Gilbert's awareness of scale effects implicit in the "area-diversity" approach (Evans 1974) and the "featured-species plan" (Zeedyck and Hazel 1974). The application of FORPLAN in a spatial context may require an understanding of landscape heterogeneity and structure which change predictably with scale.

Hierarchical Landscape Structure and Model Complexity

A growing interest in landscape ecology has prompted ecologists to view ecosystems in a spatial context (Naveh and Lieberman 1984, Risser et al. 1984, Forman and Godron 1986). Landscape studies emphasize the effects of heterogeneity on the flow of organisms and resources between ecosystems. Of primary interest are the relationships between the spatial and temporal scales at which ecosystem processes vary.

Urban et al. (1987) develop a fundamental relationship between the spatial and temporal extent of landscape entities; a relationship first described by Delcourt et al. (1983), but anticipated by Shugart and West (1981). Specifically, small landscape entities, such as canopy gaps created by tree falls, have a very short life span, while landscape features spanning hundreds of hectares persist for much longer periods of time. Therefore, the landscape is viewed as a hierarchy (Allen and Starr 1982, Allen et al. 1984), with small, dynamic entities layered over large, slowly changing entities. The static nature of large encompassing entities forms a constraint on the behavior of small entities.

Foresters recognize this hierarchical pattern at all levels. Each Forest is unique at the continental scale, most likely because major environmental factors such as geological features, precipitation, temperature, and insolation vary complexly throughout the United States, providing a unique combination of conditions at each Forest. Within Forests, topographical, geological, and historical patterns create unique conditions among watersheds, thus constraining the types of forests possible within these smaller regions. Environmental constraints are the slowly changing conditions of large entities within which small landscape elements exist.

Consistent changes occur in the structure of landscapes as a function of scale for areas about the size of a typical National Forest. Here, landscape "structure" is the "spatial relationship among the distinctive ecosystems or 'elements' present" (Forman and Godron 1986), where elements include common entities such as meadows, streams, ponds, and wooded patches. The scale-dependency of landscape structure means that landscape characteristics (e.g., the diversity of landscape elements) vary with the spatial scale used to make the measurements (fig. 1). The slope of the relationship is constant for a given landscape (within a specific range of length scales). Thus, the slope of the line is a "scale-independent" (Mandelbrot 1983) characteristic of a landscape. This relationship reflects the hierarchical arrangement of small, dynamic patches within large, slowly changing patches, such as entire watersheds.

Scale-dependent landscape structure suggests a possible limitation of FORPLAN when applied in a spatial context (e.g., Armel 1986, Ryberg and Gilbert 1986). A scale-

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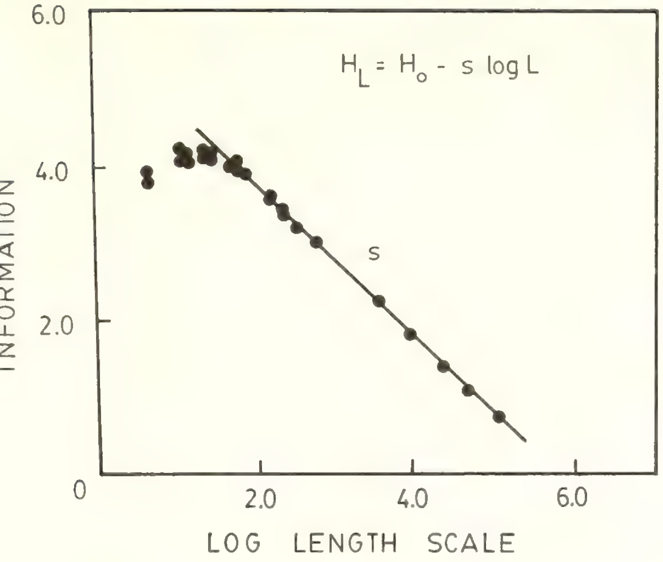
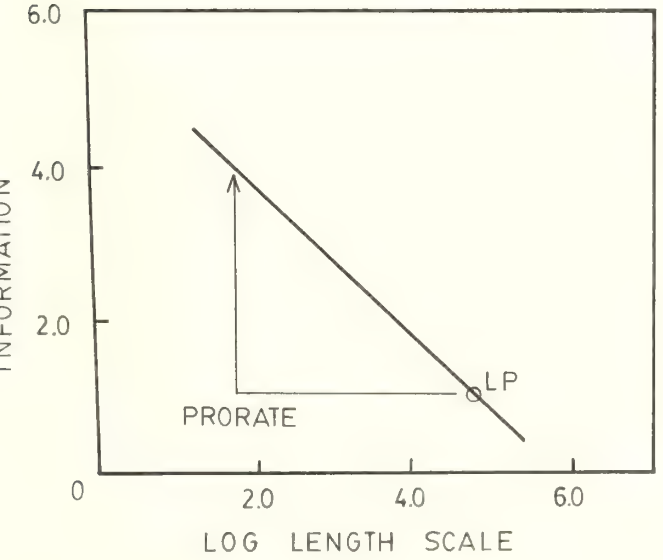


igure 1.--The diversity of landscape elements present (e.g., forests of various types, clearings, streams) in an approximately 22,750-acre forested landscape in New Brunswick, Canada. Diversity, measured using the Shannon-Weaver Index, varies with the spatial scale at which measurements were made. Broad-scale measurements were based on aggregations of data available at the finest spatial scale. Only the slope of the curve is independent of the spatial scale.



igure 2.--Scale-dependent landscape structure may preclude prorating the predictions made at one scale to other scales. Here, the diversity of landscape elements varies with spatial scale (fig. 1). Therefore, specifying a certain diversity level at one scale as a constraint in the FORPLAN linear programming module (point LP) may result in drastic underestimation of diversity when the results are prorated to finer scales. The appropriate diversity level at each scale is determined by the slope of this relationship for a particular landscape. Here, broad-scale measurements are based on aggregations of data available at the finest spatial scale.

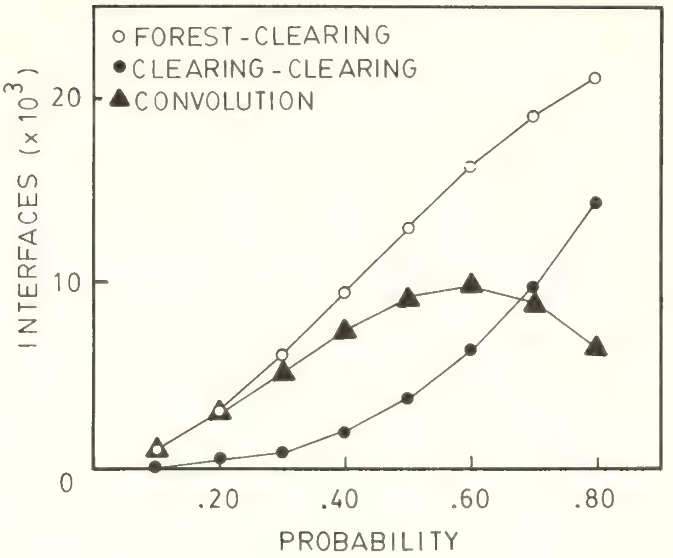


Figure 3.--The numerical difference (convolution) between (1) the number of clearcut-to-forest interfaces and (2) the number of clearcut-to-clearcut interfaces in a forest modeled as a random percolating network. At approximately 60% cutting the proportion of clearcut-to-clearcut interfaces begins to approach the greater portion of the total interfaces. Aggregation of data at different scales may shift the modeled landscape along the abscissa, thus changing the interface consequences predicted from percolating network geometry.

dependent relationship may be anticipated for both the parameters and yield streams of FORPLAN, just as the diversity of landscape elements may change with the scale at which measurements are made (fig. 1). A major discrepancy between the predictions of the model and the intended prescription (specified by the National Forest Management Act) may occur when the results are applied to the Forest as a whole. For example, if species, or landscape, diversity in an approximately 40 ha area is used as a constraint to determine yield or profits, application of the model's predictions may be inappropriate when applied to a different spatial scale, such as the entire forest (fig. 2). At the very least, prorating diversity values to broad areas without consideration of scaling relationships may degrade the integrity of the landscape as a whole.

Effects of scale-dependent structure need to be considered when data are aggregated at broad scales to reduce the complexity of the matrix entered into the linear programming module. To see why, consider that spatially complex landscapes may be represented as "percolating networks" (*sensu* Orbach 1986) exhibiting truly remarkable properties. The simplest percolating network is a set of points on a lattice, with the probability of a point being present determined by an arbitrary threshold, $0 \leq p \leq 1$. If vacant points represent clearcuts, and occupied points are viewed as forest, then a dramatic effect on the number of potential interactions between forested and cleared land is associated with the critical probability of 0.5928. Surprisingly, when the probability of clearing is ≥ 0.5928, there will appear a cluster of cleared areas so large that it spans the width of an infinite plane (Orbach 1986). Also at that threshold, the relative number of interfaces between forest and clearcuts begins to diminish compared with the interfaces between clearcut patches (fig. 3).

Granted, the average density of clearcuts is rarely, if ever, equal to 59%. However, the aggregation of data at different scales, to reduce the complexity of the matrix input to the linear programming routine in FORPLAN (Barber 1986, Navon et al. 1986), may alter the consequences of percolating network geometry for estimations of yield at broad spatial scales. This occurs because a landscape is finite in area, and aggregation at coarse scales may result in finite clusters because of "sampling" effects which occur at coarse grid sizes. Therefore, the interfaces between large landscape entities (some of which result from the management regime) may obey the relationship in figure 3 based on a different probability value than the original fine-scale percolating network. Aggregation of data at different scales is an effective means of reducing model complexity, although it may drastically alter the interactions occurring among extensive landscape entities, such as watersheds.

In summary, landscapes have a hierarchical scale-dependent structure. Small entities exhibit rapid changes compared with large entities. As a result, broad-scale features (e.g., mountain ranges, watersheds) form the long-term context for smaller entities, such as clearcuts and canopy gaps. A growing interest in spatial applications of FORPLAN (Armel 1986, Ryberg and Gilbert 1986) suggests that special strategies are needed for building models sensitive to the hierarchical structure of landscapes. Next, I suggest several possible technical solutions to problems inherent in adopting a hierarchical paradigm.

Potential Modeling Strategies Reflecting the Hierarchical Structure of Landscapes

Lagrange Multipliers and Hierarchical Models

The scale-dependency of landscape structure implies that simple, linear extrapolation of model results obtained at one scale to other scales may not ensure that the necessary yields or amenities are obtained. Granted, the unique nature of each Forest demands that the application of FORPLAN be tailored to each location. However, a set of independent models and prescriptions may not combine to satisfy the national-level mandate of Congress put forth by the National Forest Management Act (Haimes 1977). Individual Forests face the same problem if optimization is done for individual analysis areas (e.g., Armel 1986). The optimal solution for a local management unit may be incompatible with the long-term goals of the Forest.

Similar problems occur in water resources management, and the hierarchical approach developed by Haimes (1977), and provided below in slightly modified form, seems appropriate for the extension of FORPLAN to a series of specific, interacting, management units. The key to this approach is the Lagrange multiplier, which helps link several small models hierarchically. It has the added benefit of accommodating nonlinear constraint equations, which perhaps should be considered as candidates for improvements to the current FORPLAN.

In essence, given an optimization problem with one decision variable, x, and the requirement to find

$$\min f(x),$$

with the constraint

$$g(x) = b,$$

the Lagrangian function, L, is defined as

$$L(x,\lambda) = f(x) + \lambda\,[g(x)-b]$$

where λ is a Lagrange multiplier. Specification of the stationary points of L yield two equations for the unknowns, x and λ:

$$\frac{dL}{dx} = \frac{df}{dx} + \lambda \frac{dg}{dx} = 0$$

$$\frac{dL}{d\lambda} = g - b = 0$$

Solving for the stationary points of the equations gives x^* and λ which can be equated to min f(x) (Haimes 1977).

Application of this approach to landscapes requires a series of models for individual analysis areas (considered here to be precise geographic locations), with knowledge of the couplings between adjacent areas. Couplings might include the amount of energy, money, silt, water, and nutrients flowing from one analysis area to another. Then, as described by Haimes (1977), a hierarchy of Lagrange multipliers is developed to coordinate the analysis area models into a complete, optimized Forest system. Most important, the solution to such a model differs from the solution obtained by prorating a single Forest-wide model to smaller landscape units.

Nonlinear High Order Markov Models

Landscape dynamics are relevant to discussions of wildlife habitat and resource management. The appropriate habitat for a species shifts spatially through time as successional plant communities age, so a dynamic model would be helpful. Two aspects of landscape structure and dynamics suggest limitations of simple Markov models besides those shown by Shugart and Gilbert. These limitations may be reduced or eliminated. First, the "rules" applied to a landscape change through time because of Congressional mandates, public opinion, or Forest Service policy. Thus, the transition probabilities describing the likelihood of change from one cover type to another also change. Simple Markov models have constant transition probabilities, making them insensitive to changes in the rules controlling landscape change.

Second, neighboring patches may affect the transition probabilities of particular patches. For example, the staggered cutting method precludes the clearing of uncut timber if it is next to an existing clearcut. Damage from windthrow or fire may occur if a stand is next to a clearcut (Jerry Franklin, personal communication). Thus, a "neighborhood" effect should be incorporated into Markov models. This is done using "conditional" transition matrices, where the probability of changing from one cover type to another is conditional, or depends, on the identity of the adjacent patch. Dr. Jean Hartman, at Harvard University, and I are developing such a landscape model incorporating both dynamic and conditional transition matrices. The greatest assets of Markov models are that few parameters and small amounts of data are required for simulation (compared with forest gap models). Thus, Markov models are a practicable way of reducing the number of variables required.

Wildlife Habitat, Bayesian Models, and Geographic Information Systems (GIS)

Managers often require knowledge of the precise location of animal populations or resources (Connelly 1986). Correlational studies of wildlife habitat (discussed by Shugart and Gilbert) may not provide such information, or it may be difficult to translate correlational relationships to maps. Bayesian classification provides a simple, alternative method for determining the most likely habitat locations for wildlife. Once developed, this technique could be readily applied to GIS-based versions of FORPLAN (Stephan 1986), and to FORPLAN coupled with a simulator of landscape dynamics, such as the Markov model described above. Precise predictions of wildlife habitat locations could be made using such versions of FORPLAN.

A Bayesian model requires maps of cover types and other landscape features such as slope and elevation. Each point on the landscape is described by a vector, **x**, containing the list of features present. Then, the "state" of wildlife populations, **w**, of each point on the landscape has a probability of occurring, conditional on the vector of landscape features. Examples of states include "wildlife species present" and "wildlife absent." According to Bayes' formula,

$$P(\mathbf{w}_j|\mathbf{x}) = \frac{p(\mathbf{x}|\mathbf{w}_j)\,P(\mathbf{w}_j)}{p(\mathbf{x})}$$

where

$$p(\mathbf{x}) = \sum_{j=1}^{n} p(\mathbf{x}|\mathbf{w}_j)\;P(\mathbf{w}_j).$$

Here, $p(\mathbf{x}|\mathbf{w}_j)$ is the state-conditional probability density function for $\mathbf{x}$, $P(\mathbf{w}_j)$ is the *a priori* probability of state $\mathbf{w}_j$, and $P(\mathbf{w}_j|\mathbf{x})$ is the *a posteriori* probability of each state, given the set of landscape features present.

Neighborhood effects could be included in the vector of landscape features, if such effects were shown to be important. This model of wildlife habitat is easily applied using a GIS, and may be tuned to incorporate consequences of landscape structure. The sensitivity of this approach to the hierarchical structure of landscapes is not known, except that the model would probably provide less predictability if only very coarse resolution habitat information were available or if species sensitive to fine-scale habitat variation were of interest (MacArthur 1972).

In summary, recognition of complex spatial structure in landscapes requires special approaches to landscape modeling. Interactions between adjacent (and perhaps distant) patches precludes simple prorating of estimates over wide areas, or among locations with vastly different environments. Hierarchical models reflecting the scale-dependent structure of landscapes may be effective means of extrapolating from fine- to broad-scale predictions. In some applications, landscape dynamics may be simulated using enhanced Markov models, with the advantage of using many fewer parameters than are necessary in models based on gap dynamics. Twenty years ago few people would have envisioned the present capabilities of FORPLAN. There is every reason that future versions will be sensitive to the hierarchical structure of landscapes, and incorporate knowledge of the surrounding patches to predict changes within particular patches.

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An Evaluation of FORPLAN from an Operations Research Perspective

B. Bruce Bare and Richard C. Field[1]

Abstract.--FORPLAN is a computer system for developing linear programming models in support of National Forest planning. Technically, most deficiencies of LP can be overcome to correctly produce large-scale comprehensive models. However, the validity, reliability and usefulness of these models are in doubt because their opaqueness may exceed the analysts' ability to adequately interpret them for use in supporting politically-charged decisions. Better definition of the planning problem and closer tailoring of the analytical support is suggested.

Foreword

The following evaluation of FORPLAN is offered in an effort to explain some of the characteristics of National Forest planning and to make future improvements in the planning process. While at times critical, our comments are not directed at any region, forest or individual. To the contrary, we recognize the many fine accomplishments of a large cadre of men and women who worked tirelessly to develop, improve, and implement FORPLAN during the past few years. The many accomplishments attributable to FORPLAN are exclusively the result of their efforts. We also recognize that our evaluation is blessed with the added advantage of hindsight. Thus, the faults we find must be interpreted in this light. Finally, we acknowledge the direct and indirect help of the many people who have been involved in the development, refinement, maintenance, and implementation of FORPLAN.

Introduction

Perhaps the most difficult part of this paper will not be the evaluation of FORPLAN, but determining what is an "Operations Research" (O.R.) perspective. The president of the Operations Research Society of America, Stephen M. Pollock (1986), speaking to the diversity and broad charter of operations research recently said that, "... the great trinity of O.R.: problem solving (agenda setting, fixing goals and objectives); decision making (evaluating and choosing); and the necessary mathematical apparatus needed to achieve this (name your favorite technique, algorithm or heuristic) ... [leads to] ... the almost hubristic willingness of most operations researchers to attack normative or descriptive problems of the widest conceivable scope ..." Besides embracing the above listed tenets, an O.R. perspective also implies the adoption of a systems approach to problem solving. Coupled with a decision orientation and reliance on a quantitative assessment of alternatives, O.R. practitioners presume that a rational-comprehensive approach will lead to an acceptable solution to any given problem.

The past few years of forest planning have raised doubts about this last assumption. Nevertheless, with such a broad charter our evaluation could easily encompass almost everything in this symposium, and, we might add parenthetically, would be in keeping with the comprehensive nature of O.R. Further, we recognize that the analyses that natural resource economists (Krutilla and Fisher 1985) and systems ecologists (Shugart 1984) have described fall within this framework. Partly, this is because many scientific disciplines have embraced some of the tenets enumerated above, and partly it is because O.R. itself follows the scientific method. Because we do not wish to duplicate the evaluations from these points of view we must necessarily limit our evaluation somewhat.

Thus, our task is not to address the "problem" of National Forest management, or the "decisions" to be made by National Forest managers. While essential to a comprehensive evaluation, we will assume (perhaps incorrectly) that these evaluations will occur elsewhere. Instead, our objective is to evaluate the previously chosen "mathematical apparatus" -- FORPLAN: Versions 1 and 2 (Johnson 1986, Johnson et al. 1986). We will consider its technical basis and how well it has provided the information needed by decision makers. Simply put, we raise three questions: (1) Does FORPLAN work? (2) Is it the right technique and is it used correctly within the decision environment of National Forest planning?, and (3) Are the results useful? Simply put, the answers are: (1) Yes, but ..., (2) Possibly, but probably not, and (3) Occasionally.

We begin by describing the mathematical basis of FORPLAN, its inherent assumptions, and their implications. We note the "problem solving" and "decision making" difficulties that have been generated as a result of these implications, and we speculate about why FORPLAN evolved as it did and note some possible alternatives.

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Finally, we make some recommendations about addressing the "real problem," which heretofore has gone unanswered.

FORPLAN Is A Linear Programming Approach

FORPLAN (Versions 1 and 2) is a linear programming (LP) model. As such, it seeks to optimize a single linear objective function subject to a set of linear equality or inequality constraints. As described by Iverson and Alston (1986), FORPLAN is the outgrowth of a series of LP models developed and used by the Forest Service during the past 20-25 years. Without repeating this history, let it suffice to say that forest-level planning has undergone revolutionary changes during this time. Chief among these has been the legislated need for comprehensive and integrated multi-resource planning; public involvement in all phases of planning; the introduction of computerized planning models and data bases; and increased pressures on all the resources of the National Forest System.

FORPLAN is the mandated planning model in use on the National Forests and is an outgrowth of several earlier computerized planning systems: (1) RCS (Resource Capability System), (2) RAA (Resource Allocation Analysis), (3) Timber RAM (Timber Resource Allocation Method), (4) MUSYC (Multiple Use Sustained Yield Calculation Technique) (5) ADVENT (A Model for Program Budgeting), and (6) IRPM (Integrated Resource Planning Model).

All these LP models, plus others, influenced the development of FORPLAN Version 1, and subsequently, Version 2. A full accounting of this history is available in Iverson and Alston (1986), Johnson et al. (1986), Jones (1986), and Iverson (1986). For completeness, and to better understand FORPLAN and how it is used in forest-level planning, we begin our evaluation with a definition of LP along with its inherent assumptions and limitations.

What is Linear Programming?

Linear programming (LP) is a special case of the more general form of optimization techniques called mathematical programming. Mathematical programming is simply the representation of a problem in mathematical terms coupled with a formalized technique to find the optimal solution, usually without enumerating and examining all possible solutions. It is assumed that there is not a unique solution to the problem. Otherwise, there would be a mathematically straightforward -- but not necessarily easy -- way to solve the problem. Generally, a different solution technique (algorithm) is needed for different forms of mathematical expressions. Thus, there are many forms of mathematical programming and, as might be guessed, the difficulty of the algorithm increases with the complexity of the mathematical expression.

In an LP model, all the expressions have the form of linear equations or inequations and the accepted -- and until recently, the only -- algorithm for solving such problems has been the simplex. The general form of the LP problem may be expressed in matrix form as:

$$\text{Max } z = \mathbf{c'x},$$

subject to

$$\mathbf{A}\mathbf{x} \leq \mathbf{b}, \mathbf{x} \geq \mathbf{0}$$

where:

$\mathbf{A}$ is an m by n matrix of constraint coefficients ($n > m$), where m is the number of constraints and n the number of decision variables.

$\mathbf{b}$ is a vector of m constraint levels,

$\mathbf{c}$ is a vector of n optimization criterion weights,

$\mathbf{x}$ is a vector of n decision variables,

z is the scalar value of the objective function,

$\mathbf{0}$ is a vector of zeros.

An LP problem is likely to have an infinite number of infeasible solutions (do not satisfy the constraints) and, it is hoped, at least one and possibly an infinite number of feasible solutions (within the decision space). The simplex algorithm (Dantzig 1963) first finds a feasible solution, then makes systematic moves to other feasible solutions if it can improve the value of the objective function. If it cannot, it assumes it has found the optimal solution and stops. There may be other feasible solutions known as alternative optima which have the same optimal value of the objective function, but differ in decision space.

Solution time is a function of the number of decision variables and, more important, the number of constraints which define the decision space. Theoretically, the solution time for the simplex increases exponentially with problem size (combinations of n, m and non-zero constraint coefficients), but it rarely does so in practice. A radically different algorithm developed by Narendra Karmarkar of Bell Labs promises to do even better because its solution time appears to be polynomially, rather than exponentially, bounded. However, its performance has not been as spectacular as hoped and it has not been tested on a full array of LP problems (Hooker 1986). Whatever the outcome of the battle of the algorithms, very large problems are not likely to be solved by either method in a reasonable amount of time.

LP Assumptions and Limitations

Although the assumptions of LP are well known (e.g., see Dykstra 1984 or Kent 1980), the implications of these assumptions are not usually consciously considered by O.R. analysts or the general users of LP models. However, the interpretation of results and their implementation by on-the-ground managers depend heavily on these assumptions and their relationship to the "real world." Recently, Wilson (1986) reviewed the implications of these assumptions within the context of FORPLAN. We wish to pursue this topic in more detail.

First, because of its linearity assumption, LP is often criticized as being too simplistic to model many real world phenomena. "The world is not linear!" This is an oft heard battle cry, and is generally a valid observation. But, the implication of linearity that is most often challenged is proportionally. This deficiency can be effectively overcome with proper formulation. For example, FORPLAN handles nonlinear timber yields with ease. Dealing with nonlinearities in the constraints and the objective function are admittedly more difficult. However, more complex algorithms can be used (e.g., quadratic programming), or the nonlinear constraints can be handled in a piece-wise linear fashion (Hrubes and Navon 1976). Such is the case with FORPLAN demand constraints.

However, the more insidious implications of linearity often are overlooked. These are the additivity and divisibility assumptions. Additivity means that any combination of feasible values for the decision variables produces a consequence which is the sum of the individual values. No interactions are permitted to cause variations from this total. The second implication -- divisibility -- allows a decision variable to take on a continuous range of values. In many LP models, however, integer-valued decision variables are required (e.g., FORPLAN Version 2 with coordinated allocation choices). To permit a noninteger value implies infeasibility in the real world, making such a solution difficult to implement.

LP does not allow interactions and it does not guarantee integer solutions. More often than not, these are important considerations in forest-wide modeling as found on the National Forests. Careful formulation of the model and cautious interpretation of the solutions may allow one to avoid incorrect results without resorting to more complex and costly alternatives such as nonlinear and mixed integer programming. However, this is doubtful with large, complex models such as FORPLAN, especially Version 2 with coordinated allocation choices.

Another commonly cited criticism of LP is that it is deterministic. This is because probability functions, which are often nonlinear, are impossible to incorporate into LP models. Hence, all coefficients in an LP model are assumed to be known with certainty. If we attempt to incorporate uncertainty into an LP model, both model size and solution time increase dramatically. Thus, probabilistic elements are usually omitted from LP models.

A final weakness of LP is that it explicitly assumes there is a single decision criterion to be optimized and implicitly assumes there is a single decision maker. Neither of these generally hold for the National Forests in practice or for public decision making in general. There are many algorithms, procedures, and alternative modeling techniques to overcome these deficiencies. National Forest planning has used few of these, and FORPLAN even fewer.

As serious as these implications are, they are not a *raison d'etre* for dismissing LP out of hand. Invariably, no approach will produce a perfect model of the real world, because all models are abstractions which necessarily are simplifications of reality. However, some models perform better than others, given: first, the objectives of the modeler; second, the modeler's operational constraints; and, last, the form of the situation being modeled.

The greatest danger, then, with using LP, or any modeling technique, is not that it doesn't work perfectly, but that it is working less perfectly than the modeler (or client) thinks it is. Having a million-dollar LP model that gives results no better than could be worked out on the back of an envelope is not only a glorious waste of money, it also may be horribly misleading about the confidence that should be placed in the results. Is that the case with FORPLAN? It could be. Let us look more specifically at its assumptions, structure and characteristics and compare it to other classes of LP models.

FORPLAN as an LP: Does it Work?

From the previous discussion, we can see that LP can be deceptively simple. But the assumptions and the potential solution difficulties can not only lead to misinterpretations (as will be discussed later); they can also prevent it from working at all. It is well known that in the early days some FORPLAN models were never solved because of their size. Some were probably too large to even fit in the machine. See, for example, Barber's (1986) excellent discussion on large FORPLAN models, and the critique of Version 1 by Iverson and Alston (1986).

Given that the Forest Service was using one of the largest mainframe computers and a state-of-the-art solution code, this implies that FORPLAN models were exceeding the limits of experience in LP (Kent et al. 1986). Furthermore, FORPLAN models are generally of the most complex form of LP, known as "blending problems." Such models typically have several choices for their size and many non-zero constraint coefficients. These severely tax any solution algorithm by increasing the computations necessary to invert the matrix (an integral part of the simplex algorithm) and by requiring more iterations to find an optimum solution, which may be only marginally different from a solution arrived at thousands of iterations earlier.

To be more specific, FORPLAN Version 1, Model II forms typically have very sparse matrices (less than 1% non-zero constraint coefficients) because of the many Model II transfer rows. The Functional Mathematical Programming System (FMPS) SPRINT algorithm (Sperry Univac 1984) is designed to solve such problems very efficiently and generally does so. However, few forests use Model II except those in Regions 5, 8 and 9, and at least one forest in Region 8 exceeded FMPS's unadvertised row limit of 8,192 when it generated its matrix. The alternative Model I form was much smaller but also denser, about 8-10%. Most Model I matrices are not so dense but are still likely to be an order of magnitude denser than a nominally equivalent Model II. FORPLAN Version 2 has the ability to produce more complex models than Version 1, and thus has the potential to produce even denser matrices. We have seen them with as many as 20% non-zero constraint coefficients. This seldom occurs, however, because most Version 2 models use coordinated allocation which introduces many sparse transfer rows with a corresponding overall reduction in density.

The alternative FMPS solution algorithm, OPTIMIZE, was considerably less efficient in solving FORPLAN models. However, it was believed to produce more accurate marginal information than SPRINT, and better bases for post-optimal analyses. However, little use was made of FMPS post-optimal techniques because the time and funds that would have been necessary to perform such analyses were already committed to meeting other requirements. That limited experience suggested that such procedures were not very well documented and proved to be inefficient, the reasons for which are uncertain.

Several actions were taken by the FORPLAN developers, the Fort Collins support group and Sperry to overcome problems caused by these massive and dense matrices and to reduce solution time and cost. Kent et al. (1986) have reported on the considerable progress that has been made. With a larger, more powerful machine already on the floor and new operating systems and LP packages in the pipeline, additional improvements are also assured. But in the past it has seemed that a bigger model was just waiting to be generated as soon as the existing limits on model size or solution time were relaxed. This, too, is likely to continue albeit at a slower pace until the next cycle of planning hits. While most FORPLAN models have been satisfactorily solved -- although not always inexpensively -- we still must conclude that FORPLAN is taxing the LP state-of-the-art. To us this would seem to be an incentive to consider alternative cures of the disease rather than applying more Bandaids.[2] Thus, our answer to the question, "Does it work?" is "Yes, but . . .."

FORPLAN as a Model: Is it the Right Technique and Correctly Used?

If we conclude that FORPLAN works, then we might consider the question, "Is it the right technique and is it correctly used within the decision environment of National Forest planning?" Based on our previous discussion about the linearity and certainty assumptions we could easily answer, "No way!" However, we also could say the same thing about almost any natural resource model when compared with reality. From this standpoint then, a negative answer is too flip a response.

An astute and clever analyst can often use a crude and seemingly inappropriate model to discover some important information about a situation. Some also suggest that the "black box" approach allowed a clever analyst to produce any result that was determined "*a priori*" to be desirable. However, a not-so-perceptive analyst may use an exceedingly complex model to innocently arrive at incorrect findings. Any other combination of these types of analyst, model and results could also occur. FORPLAN produced some of all; probably more of the gross errors than of the brilliant insights. Much of what it produced was somewhere in between.

Analysts in Region 8 and elsewhere were repeatedly challenged to explain why FORPLAN produced the results it did. They were not expected to predict the results, but once they were available, they should have known where they came from. To do this, they generally had to make their models less comprehensive than had been originally envisioned.

It may be asked that if the results were so logical that they were readily explainable, was such a complex model necessary? Possibly not, but we can find examples of explainable, yet, unpredictable results that may not have been detected by a cruder model. For example, most FORPLAN models will produce the following results unless they have been otherwise constrained: they combine early profit taking with a maximum delay in costs (partially related to the allowable cut effect) which leads to markedly increasing budgets over time; they delay timber harvests for one to five periods; they assign recently cutover timberland to minimum level management; and they provide for a declining timber yield in the n + 1st period (or planning horizon plus one) if the solution is projected beyond the end of the planning horizon. These results often violate policy or law but may not be illogical given the model assumptions about resources and economics. If the model cannot avoid such results without arbitrary constraints, then something is either wrong with the model or the policies that are being violated.

A closer examination of the timber harvest delay situation illustrates the models' ability to challenge questionable assumptions. Harvest delays generally occurred because the timber price trend was assumed to be nearly as large or larger than the discount rate. In Region 8 the models' reluctance to harvest softwood in the first decade was detected early on, explained away as an historical trend that was not current and was unlikely to manifest itself in the future, and then it was by-passed with constraints. Under this argument it should have been changed, not by-passed, or at least tested with other assumptions.

In the West, this damaging assumption was even worse, because it tended to hold timber for five decades, and yet, it went undetected for years because of the complex way stumpage was calculated by the model. Eventually it was discovered and remedied with new price and trend assumptions based on more recent market information.

One wonders how many other invalid assumptions, miscalculations, or simple data entry errors lurk in these massive models. As Barber (1986) notes, large models are virtually opaque to their users and must be accepted on faith. This is a dangerous situation!

It might be instructive at this point to separate two related, yet, slightly separate aspects of the question being addressed. First, as discussed above, the "black box" nature of FORPLAN allows for data errors and hidden assumptions to go undetected. This can lead to misleading results with dubious consequences. But, apart from this, the violation of the assumptions inherent in LP also must be mentioned. FORPLAN solutions have been generated for problems which do not exist on the ground. For example, the violation of the divisibility assumption implies that many solutions require clever "interpretation," or new solutions need to be found before on-the-ground implementation can be assured. Further, the assumption of certainty is almost certainly violated in every FORPLAN run. At a minimum, sensitivity analysis is required to gauge the significance of this violation.

We suspect that these additional analyses were probably not done usually because of time and cost considerations. More than likely, noninteger solutions were "rounded off"

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[2] The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U.S. Department of Agriculture to the exclusion of others that may be suitable.

'or practical reasons. Whether such rounded solutions are even feasible, let alone optimal, seems to be a seldom-asked question. Other such violations could be cited; but our point should be clear.

Apart from these deficiencies of model solutions we must raise another important issue. Before we can answer the question of whether FORPLAN was the right model, we must determine if LP itself or the need to be comprehensive is the real concern. We suspect that much of the blame must be placed on this latter need. By placing so much emphasis on the need for comprehensive, multi-resource integrated planning, O.R. analysts working for the Forest Service were quick to conclude that only the development of a large scale model capable of handling forest-level planning over a 15-30 decade planning horizon nvolving a multiplicity of goods and services would satisfy egislated mandates as perceived by higher-level nanagement. Given this mandate, it is no wonder that LP became their chosen tool.

The analysts were given the opportunity to show the rest of the organization that "technology" would be their salvation. As previously discussed, in 1979 it is likely that the young technocrats making these decisions were largely unaware of the difficulties which lay ahead in solving the large LP problems which would result from this comprehensive approach. With hindsight, had the analysts resisted the temptation to design a single large model capable of simultaneously making land allocation and scheduling decisions, we might not have been led to this ex post facto justification of FORPLAN.

Following the agency's drive to be comprehensive, the analysts took the straightforward approach of including everything they could in one giant LP model. We wonder if a multi-stage approach might not have been a more logical and understandable approach given what we now know. We recognize that this could have been accomplished using FORPLAN as shown by Mitchell (1986); but the procedural directions tended to discourage it. While such an approach may not guarantee optimality in a model sense, it may well produce more understandable results which can be defended and implemented in the real world. This trade-off between model comprehensiveness and understandability, especially when dealing with public forest management issues (Allen and Gould 1986), needs to be evaluated before the next round of forest planning begins.

Thus, our answer to the question, "Is FORPLAN right?" is, "Possibly, but probably not." If one cannot logically explain the results outside the model, then it is doubtful that they are valid. If they can be explained, it is still no guarantee that there may be transparent formulation or data errors that are producing a reasonable but wrong answer. The best we can hope for is that by completely understanding the assumptions of LP, the formulation of the FORPLAN model, and the interpretation of the solution, we can then be reasonably confident that it is correct. We suspect that this occurred on few forest planning teams.

FORPLAN as a Planning Tool: Are the Results Useful?

You may have noted that the arguments in the previous section seemed to favor a negative response to the question posed, and yet, we arrived at a mildly positive answer. An obvious reason is that we could not have logically asked the final question if we had concluded FORPLAN to be invalid. At a minimum, we believe that FORPLAN was used as an accounting tool to accumulate the numbers that were required to be present in the planning documents. We accept that and also recognize that some simpler and more understandable approach could have been used if that had been its only purpose.

We are much more concerned with whether FORPLAN was successful in developing and supporting valid forest planning decisions that would not otherwise have occurred. From our discussions with forest analysts, planners, and supervisors, we conclude that there were some very important insights gained from FORPLAN analyses that contributed to novel and defensible recommendations for National Forest management. You will note that we did not say that they got their answers (decisions) from FORPLAN. The distinction between insights and answers from analytical models is very important and must not be overlooked (Geoffrion 1976, Brill 1979, Iverson and Alston 1986).

The forest planning procedure which required benchmark runs, a variety of diverse alternatives, and constraint analysis promoted this notion that FORPLAN was seeking information, not answers. It also helped to overcome some of the deficiencies of the approach in the area of multiple objectives and multiple decision makers. However, the prescribed minimum standards should have been merely the basis for more rigorous sensitivity analysis to gain even more confidence in the model and thus, insights into the problem. Unfortunately, the models were generally too large, the time too short, the computing budget too small, and the analytical skills too limited to allow much of this to occur except perhaps in the development of the preferred alternative.

Instead, there appeared to have been no clear understanding of the relationship between analysis and decision making. Analysts thought they should be making decisions and often did so, sometimes without realizing it. For their part, the real decision makers (forest supervisors) were more likely to reject analysis as being irrelevant, incorrect or simply threatening to their existence. Failure to do real analysis or failure to recognize the distinction between insights and answers probably led to many of the unsupportable decisions based on invalid FORPLAN results.

There was a tremendous amount of FORPLAN analysis, both good and bad, that was simply not used in making forest planning decisions, sometimes for very good reasons. It is unlikely that the amount of valid results that was used to support good recommendations exceeds the amount of invalid results that was used to support bad recommendations. Plus, there was a tremendous amount of analysis that was just plain wasted!

It would not be hard to accept the conclusion of many that the costs of FORPLAN have far outweighed the benefits. However, we are not yet ready to completely discount the future benefits to natural resources management that may be attributed to the experiences gained and the knowledge produced in this massive attempt to model our National Forests (Field 1984). Concerning valid FORPLAN results supporting defensible forest plans, we conclude that this occasionally occurred, but nowhere nearly as often as was envisioned when the planning procedures and analytical techniques were adopted.

Thus, our evaluation of FORPLAN as the mathematical apparatus for forest planning points neither to an unqualified success nor to a dismal failure. We would probably give it a grade of C-. It will be instructive to examine more closely how FORPLAN got to this point, and to consider past, present and future alternatives for the analytical support of forest planning.

Why Is FORPLAN An LP?

Given the difficulties with LP itself and its later use to model forest-level planning, as noted in the last few sections, why were these problems not recognized ahead of time and a different analytical system selected? How and why did we get into the position we are now with FORPLAN? Could it have been avoided? Were there alternative methods then, or are there now? How might forest planning be differently analyzed in the future to improve support for National Forest decision making? These questions are addressed in the following sections.

FORPLAN: An Example of the "Peter Principle?"

Iverson and Alston (1986) and others at this symposium have clearly outlined the "genesis of FORPLAN." There is little doubt about its lineage, and we do not wish to repeat it any more than we have already done. However, it seems to us that the existing recitations of FORPLAN's history have not sufficiently clarified the motivations for its being. Without such a clear understanding, we may be doomed to repeat history rather than learn from it.

The "choice of FORPLAN" seems to have revolved around four conditions as they were perceived by the Forest Service in 1979. These were:

1. The agency believed that an optimization technique was necessary to satisfy the requirements of the NFMA regulations.
2. The legislated requirement for a comprehensive and systematic evaluation of all the goods and services produced by a National Forest to maximize net public benefits led the agency to the inescapable conclusion that a large scale, forest-wide, multi-resource land allocation and scheduling model was necessary.
3. The National Forests -- and forestry -- lacked the skills necessary to leave the choice and implementation of this technique to the forest supervisors, and even were it possible, the agency would not relinquish control over the process.
4. LP was nearing the peak of its 20-year ascendancy as the accepted analytical technique for any forestry problems involving allocation and scheduling, especially timber harvest scheduling. Conceptually at least, it had already been applied to the comprehensive job of "forest management."

The Forest Service was not alone in its infatuation with LP, nor was forestry alone in its infatuation with optimization. But while much of the rest of our society was beginning to show some skepticism and disillusionment with the "Whiz Kids" of the McNamara era, the conservative forestry profession was just discovering that perhaps they could realize Pinchot's mathematically impossible dream. Meanwhile, examples were beginning to accumulate that showed the failure of many large-scale, multi-resource models (Mar 1974 and Lee 1973).

The Forest Service combined forestry's conservative nature with its own paramilitary professionalism to see the job through, and embarked on an analytical task heretofore unrivaled in the annals of operations research. This was to build a detailed mathematical model of each of the 154 National Forests and solve it to maximize the net benefits to society. Choosing LP as the optimization technique was the only logical choice that could be implemented by its personnel. Applying it "brute force" to the joint problems of allocation and scheduling was perhaps a major mistake, although it may not have been avoidable given the agency's mind-set in 1979. At any rate, FORPLAN may well have raised LP to its level of incompetence.

What Were the Alternatives in 1979?

Considering the analytical techniques that were available in 1979, there was another that rivaled LP's domination of the field (Martin and Sendak 1973, Field 1976, Elbourn 1977, Bare 1971). This approach was simulation, a very early entry into the harvest scheduling field (Sassaman et al. 1972) that was soon dominated by LP (Johnson and Schuerman 1977). Simulation continued to be heavily used in non-optimizing forestry applications, but has yet to make much headway against LP in harvest scheduling, for reasons outlined by Johnson and Tedder (1983).

There have been some improvements in both approaches by incorporating certain capabilities of the other; but Johnson and Tedder conclude that "the search continues for a technique that integrates the best features of both approaches: many inventory categories along with many harvest constraints using a search procedure that guarantees attainment of the optimal solution." Whether this idyllic method will emerge for harvest scheduling says nothing about its possibilities for the much more complex job of comprehensive forest planning. Furthermore, the decade of the 1970's brought much doubt about the viability of large scale simulation models for aiding decision makers faced with complex environmental and land use issues (Mar 1974). There was little chance that simulation could do the job in 1979.

Other optimization techniques had been applied to forestry problems. Some were completely different mathematical programming techniques, such as dynamic programming (Hool 1966), control theory (Anderson 1976), nventory theory (Pelz 1977), integer programming (Bare and Norman 1969), and quadratic programming (Romesburg 1974).

There were also a few variations of LP, most notably attempts to address decision making under uncertainty with probabilistic LP (Thompson and Haynes 1971). Attempts to overcome the problems of LP model size by decomposition echniques were reported as early as 1967 by Liittschwager and Tcheng. Almost without exception, these reports and he similar efforts which followed them were experimental n nature and never saw even limited application, at least in he arena of optimal harvest scheduling which fathered FORPLAN. Another variation of LP, network analysis, was seeing considerable application in transportation planning and its even simpler forms of PERT and CPM were being routinely applied to project planning problems.

Other analytical approaches applied to forestry problems included input-output analysis, decision theory, nonlinear programming and separable programming. None seemed able to address the scale of problems found in forest planning or the conditions for optimality. Possible contributions to problem definition, to generating planning alternatives, and for refining planning procedures appear to have been overlooked.

During the 1970s, the area of multiple criteria optimization was being rapidly developed. Forestry became enamored with goal programming (GP) from the work of Dave Field (1973). Its application to land management planning seemed to be particularly attractive (Bell 1976). While certain problems were noted with its application and nterpretation (Bell 1975 and Dyer et al. 1979), a GP system was installed at Fort Collins for the use of Forest Service planners (Bottoms 1976).

Largely because of a complementary LP and GP procedure developed by Field et al. (1980) that appeared to overcome these problems, GP options were incorporated in he FORPLAN system. These options were seldom used except by several forests in Region 8 to develop alternatives n the face of conflicting objectives. One other multiple criteria approach, multiple objective linear programming (MOLP), had been applied to a forestry problem (Steuer and Schuler 1978) with limited success on a small scale. Most of the other approaches which were gaining wide acceptance in water resources planning (Cohon and Marks 1975) have yet to receive much attention from forestry.

The modeling technique which would seem to have the most useful application to the problem addressed by FORPLAN was some form of decomposition. Most of the work after Liittschwager and Tcheng (1967) involved specialized combinations of LP, DP, and Dantzig-Wolf decomposition (Nazareth 1980, Williams 1976, and de Kluyver et al. 1980). These approaches, like the other optimizing procedures discussed above, would have been difficult, if not impossible, to implement under the Forest Service's conditions for modeling.

However, Dress (1975) had proposed a more generalized, two-stage approach to forest planning which did not win the FORPLAN sweepstakes (Jones 1986), but was sanctioned for use with FORPLAN in Region 8. A system to perform the first stage, steady-state analysis (Steady-State Analysis Model, SSAM) was developed (Field et al. 1981) but its linkage to FORPLAN was never established. This and the exhaustive efforts necessary to develop the required FORPLAN models prevented SSAM from ever being applied. At the same time, there was a concerted effort by the FORPLAN developers to head off any efforts to challenge FORPLAN's role as the simultaneous allocation and scheduling model (Crim 1982). As a result, the only innovative, multi-stage forest model that has been developed to date is Tom Mitchell's (1986) Shoshone model. This approach appears to have sufficient merit to warrant critical evaluation (Connelly 1986).

Considering the private industrial forestry sector before 1979, there were even fewer reports of successful applications of modeling systems other than LP and simulation. Comprehensive and integrated efforts the size of FORPLAN had not yet been attempted in industry and most that would be tried in the next 5 years would fail. Thus, in 1979, the decision to use an LP system for forest planning was principally because of the lack of any tested and experienced approach other than the harvest scheduling models of industry and the Forest Service, as postulated by Ware and Clutter (1971) and Navon (1971).

There was apparently no attempt to consider other modeling systems outside forestry or even in the broader field of planning. Given that such systems would have to be tested and proven in forestry, and that Forest Service personnel would have to be trained in their use before they could be applied, this lack of consideration may be justified. The observation that with FORPLAN the Forest Service was "trying to build a bicycle and ride it at the same time," would have been even more appropriate had the agency selected an approach with which the profession had no experience.

Forest Service analysts were justified in selecting LP as their prime "mathematical apparatus" to drive the forest planning process. However, as already stated, the major flaw rested with the decision and (yes) the desire to satisfy the need for comprehensive analysis by building and solving a single, large scale LP model with thousands of rows and tens of thousands of columns. Apparently, insufficient thought was given to two fundamental questions: (1) Was the model to be used to guide strategic, tactical, or operational planning?, and (2) How relevant would model results be to on-the-ground managers and how easy would it be to explain model outputs?

As a result of this, we have today the FORPLAN system which produces models which:

1. Are too large, too poorly understood, and too costly in terms of set-up time, solution time and user skills to have been more than of limited value to the present planning efforts and little or no value to support decisions in the future.

2. Do not adequately address the different but linked problems of forest planning: strategic (allocation), tactical (scheduling), and operational (implementation).

3. Do not recognize or comfortably fit the real process of making decisions on the National Forests which is more political than analytical.

What advances in analytical methods have occurred since 1979 that may help overcome these deficiencies?

Where Are the Alternatives Now?

It would appear that mathematical programming has become deeply embedded in the tool kit of the natural resources analyst. Witness a text book devoted entirely to the subject recently published by Dykstra (1984). Meanwhile, experimental work has continued in at least as many modeling areas as were identified in the previous section. Among these are methods to reduce large models (Barber 1985 and Navon et al. 1986), new decomposition techniques (Berck and Bible 1984 and Hoganson and Rose 1984), additional applications of multiple criteria optimization (Allen 1986, Bare and Mendoza 1987, and Arp and Lavigne 1982), and applications of generalized network analysis to natural resources management (Glover et al. 1984). Holling et al. (1986) have successfully shown a blend of simulation and optimization where a simplified Markov-process optimizer serves as the "brain" for a large-scale ecologic simulation model. Hoganson and Rose (1984) take the opposite approach and solve a large-scale LP model by simulation techniques.

Among the new approaches that have been introduced is the use of heuristics with mathematical programming (Navon and Weintraub 1986). Swindel (1984) suggested game theory for some aspects of forest management planning and McLean (1983) recommends a systems approach called positional analysis. This is just a sample of the considerable work that has been done in the last 5 - 10 years. Four large compilations of this work in forestry are Harrison and de Kluyver (1984), Bare et al. (1984), Kallio et al. (1986), and Field and Dress (1986). There are also tremendous resources outside forestry; for example, a compilation of papers on optimization models for strategic planning by Naylor and Thomas (1984).

There also have been at least three reports of successful applications of LP to integrated industrial forestry problems. The first is a non-partitioned model described by Barros and Weintraub (1982). Notably, it is a very small model (1000 rows by 2500 columns) compared with most FORPLAN models. Most other integrated industry models have failed because of problems similar to those encountered in National Forest planning: size, lack of data, uncertainty, and unmodeled political realities within the organization.

Hay and Dahl (1984) have apparently overcome these problems with a successful modeling of strategic and tactical planning in Weyerhauser's southern operations. They use LP models for each phase; but they do not appear to be explicitly linked except by common data and assumptions. Both are small, the strategic model being the largest with about 900 rows and 7000 columns. It contains aggregated versions of the smaller tactical models which may have as many as 350 rows and 700 columns.

The final report by Weintraub et al. (1986) describes an application similar to Hay and Dahl. However, they give considerably more attention to validating the linkage between the strategic and tactical models and use mixed integer programming techniques to solve the strategic model. This approach was introduced by Nautiyal et al. (1975) but has seen little use in forestry, despite its logical application to strategic decisions of an "all or none" nature. Weintraub et al. show the applicability of a hierarchical approach to forest planning and prove it to be mathematically tractable. Hof and Pickens (1986) recently tested a similar application to public resources planning with mixed, but potentially promising, results.

The lesson from Weintraub et al., Barros and Weintraub, Hay and Dahl, Hof and Pickens, and Mitchell's Shoshone model seems to be that if one recognizes the hierarchical nature of planning and uses separate models, tailored to each specific phase of planning, there is more chance for successful support of management decisions. A considerably more rigorous and risky alternative would be to adapt some large-scale systems approach involving optimization, simulation, heuristics, and formal decomposition procedures. Such an approach is unlikely ever to be within the capabilities of the Forest Service to develop, implement and manage.

Conclusions and Recommendations

The Forest Service choice of an analytical model to aid National Forest planning, FORPLAN, was logically supported by the limited availability of optimization techniques that had been applied to forestry; by the analytical skills available to the agency; and by the limited time necessary to complete the plans. Technically, the LP approach would have been acceptable had it been properly applied (i.e., recognizing the hierarchical nature of planning and its relationship to decision making) with a complete understanding of its limitations and their implications. This was, unfortunately, seldom the case. As much to blame for this failure may be a misinterpretation of the planning problem that the agency faced.

It is sometimes convenient to blame a plane crash on mechanical failure when it was pilot error. Let us be careful not to blame FORPLAN for all the evils of forest planning. FORPLAN was the product, not the producer, of comprehensive forest planning. Irland (1985) has noted that "comprehensiveness is a trap ... comprehensive planning fails to sort the strategic from the trivial, wastes resources on secondary concerns, paralyzes the will in the face of complexity, and bogs down in empirical debates for lack of direction." Allen and Gould (1986) further detail these criticisms in irrefutable fashion. As discussed above, we too believe this to be the major flaw in the development of most FORPLAN models.

Before any attempt is made to extend, improve, correct, or change the existing analytical apparatus, the relationship between the hierarchical nature of planning and decision making in the Forest Service must be completely and satisfactorily resolved. As previously noted, this issue is beyond the scope of this paper and this symposium; but it must be addressed before any rational selection of tools to support it may be made.

A team of decision makers and planners should study the agency's accomplishments and failures in planning, expected futures for the agency, and the use and success of planning in other organizations; and propose a new framework for planning in the Forest Service. It is important that this team is aware of changing philosophies in planning as noted by Gluck (1985) to avoid hopping on the bandwagon just as the horses are being unhitched. Equally important is to be aware of the dangers of poor implementation (Gray 1986). Recognizing that planning is the continuous technique of adapting the organization to its environment (Michael 1980), every effort should be made to integrate planning with management (Meising 1984).

Some knowledge of the capabilities of planning tools will be useful in this self-examination; but it must not be allowed "to drive the solution" as it may have from 1976 to 1979. Many believe the need for optimization and the benefits of LP were greatly oversold. They are probably correct. Forest planning may have been a nail that could have been very effectively driven with a hammer. But we had learned to use a fancier tool, a screwdriver, so we filed a slot in the nailhead. Try driving a slotted nail with a screwdriver - it will not work. Maybe that is what happened with FORPLAN and forest planning.

However, it is likely that current or near future capabilities in the storage, retrieval and manipulation of information will dramatically alter planning and decision making. Examples are the ever-increasing capabilities of micro systems available to remote users, low-cost geographic information systems, practical systems involving artificial intelligence, and the underexploited power of parallel processing. These implications must not be ignored for they are certain to change, if not eliminate, the role of many staff functions and middle managers.

Once planning is defined, a task force of decision makers, planners and analysts should be appointed to completely specify the analytical support necessary. Part of this specification must be the level of administrative support that will be assigned to the planning function. This includes authorizations for hardware, software, maintenance, analytical skills of the users, and managerial time to work closely with the planners and analysts. These specifications, once approved by agency leadership, should be issued in the form of a "Request for Proposal" of a planning support system for the Forest Service. Proposals should be carefully examined for compliance with the specifications, proven technology and expected reliability. The best, but not necessarily lowest, bid system should be purchased and installed.

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Evaluation of FORPLAN from an Operations Research Perspective: Discussant's Comments

Dennis P. Dykstra[1]

The paper by Bare and Field (1987) provides a useful overview of the technical considerations relevant to an evaluation of any large-scale, applied programming model. will not comment on their opinions about the motivations hat led to the adoption of FORPLAN because such speculations do not seem to me to be particularly relevant o the evaluation of FORPLAN as a technical entity. For he most part their discussion of the technical aspects of planning with FORPLAN agrees largely with my own preconceptions, so my remarks are confined to a few points hat I think require additional clarification. These points fall into three categories: data errors, the definition of analysis areas, and hierarchical, or multi-level, planning.

Data Errors

As Bare and Field have stated, no large-scale programming system is ever likely to be completely free of ogical and programming errors. The important thing is that he code should be free of errors that might have a significant impact on the problems being solved. I must admit that my experience with FORPLAN has only been second-hand, and, therefore, I am more than happy to accept the judgment of Bare and Field that, with a few possible exceptions, FORPLAN seems to be free of significant errors of this type.

However, broadly as they have interpreted their "operations research perspective," Bare and Field have little to say about **data** errors, which I consider to be a potentially much more devastating problem than programming and logical errors.

Data errors tend to be serious because of the likelihood that they will escape detection. In a model such as FORPLAN it is reasonably likely that logical and programming errors will be caught at some stage, especially because there is a large community of users, unless the errors themselves are sufficiently innocuous that they don't matter very much.

The kind of data errors that are most insidious are **not** data-entry errors, which can usually be discovered by carefully auditing data files. Rather, the most serious data errors are those of **measurement** and **classification**. Measurement errors are the most fundamental, and affect all resource decisions. There is little that FORPLAN analysts can do about such errors, because the analysts are not the ones charged with making the measurements. For certain kinds of resources, such as timber, the Forest Service has developed reasonably good procedures for avoiding such errors and we can probably be confident that most existing measurement errors related to timber resources are at the very least unbiased.

For non-timber resources, though, the situation is not so clear. Conventions relating to the assessment of recreation potential, aesthetic resources, soil erodibility, wildlife habitat, water yield potential, range condition, and other non-timber resources have not been clearly established. These assessments are subject to large measurement errors, if we are even willing to refer to the kinds of judgments commonly used in making these assessments as "measurements." Although work underway at the Rocky Mountain Forest and Range Experiment Station's Multiresource Inventory Project should help define appropriate measurement procedures for non-timber resources, the current round of NFMA planning lacks any such comprehensive guidelines. As a result, the data used in making FORPLAN runs is inevitably flawed because of substantial (and unknown) differences in the variance associated with estimated resource levels (and projections over time) for timber and non-timber resources. Because the planning effort is specifically directed at multiresource analysis, this appears to me to be a very important difficulty. It is **not** inherently a FORPLAN problem; any multiresource planning method that attempts to do planning at the level of detail prescribed for the FORPLAN analyses would face the same difficulty.

Classification errors, as contrasted with measurement errors, may result directly from the FORPLAN analysis itself. The FORPLAN analysis requires that certain decisions be taken by the planning team, and these decisions will have a profound effect on the results. One such decision is the identification of analysis areas.

Analysis Area Definition

Recently, together with some of my colleagues at Northern Arizona University, I've been reviewing the plans of several of the National Forests in Arizona. One thing we've noticed is that different forests have used completely different approaches, based on an entirely different set of assumptions, in the definition of analysis areas. On one Arizona national forest, for instance, the planning team made a considerable effort to recognize the spatial distribution of resources as one element in the definition of analysis areas. For the most part, their analysis areas are contiguous because the planning team felt that the plan should reflect the way the forest is managed. The planning team of another Arizona national forest, in contrast, used a more conventional forest strata approach in identifying analysis areas, so that a single analysis area is made up of small pieces scattered all over the forest. I suspect that this is typical of the way most national forests have identified analysis areas.

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The reason I believe this point is important is that it will influence, perhaps markedly, the results of the FORPLAN runs, particularly the calculation of present net worth. If you require that analysis areas be contiguous, you construct an implied constraint that will restrict the feasible region and possibly reduce the calculated present value of certain or all the alternatives being tested. This fact has often been given as a reason for permitting analysis areas to be non-contiguous. That's well enough if you can manage the forest in small, scattered pieces, but if operating plans concentrate on larger, contiguous blocks, then the implied constraints ought to be in place. Otherwise FORPLAN, or any other planning method, will overestimate net present value.

A final point about the definition of analysis areas, based on research in multiresource management we have underway at Northern Arizona University, is that different resources may require different definitions of analysis areas. Wildlife, for instance, do not respect the vegetative boundaries that have commonly been used in defining analysis areas for FORPLAN runs. Proper consideration of overlapping analysis areas for different resources will require implementation of overlay methods similar to those used in geographic information systems.

Hierarchical (Multi-Level) Planning

From discussions I've had with several forest planners, my impression is that one of the worst features of the current round of NFMA planning is that many of these planners and their colleagues on the planning teams have been "burned out" by the experience. I suspect that this is largely because of the level of detail required in the planning effort. This requirement has led to the necessity to develop and process vast quantities of data, and has resulted in FORPLAN models with an enormous appetite for computer time and disk space.

I agree with the assessment of Bare and Field that FORPLAN, as used by most national forests, does not adequately address the different but related problems of forest planning: strategic planning (allocation), tactical planning (scheduling), and operational planning (implementation). It seems to me, however, that their recommendation does not go far enough. I believe rather strongly that to support its future planning efforts, the Forest Service should adopt a planning system that specifically recognizes these distinct but interrelated levels of planning. Strategic planning ought to be done at a regional or national level, and it should use an appropriate level of resolution, recognizing that the kind of detail needed to manage individual forests is unnecessary for strategic decisionmaking, and merely gets in the way. Tactical planning ought to be done at the forest level, with a higher level of resolution, and operational planning at the district level. This final level of planning should be very site-specific and should rigorously maintain spatial integrity. It is at this level that planning and management should be fully integrated, and not at the higher levels.

Hierarchical planning of this sort is similar to the multi-level optimization concept being developed by Tom Hoekstra, John Hof, and their colleagues in the Land and Resource Planning Project at the Rocky Mountain Forest and Range Experiment Station. This type of approach to forest planning and multiresource management seems to me to be far superior to the single-level approach typified by most current applications of FORPLAN.

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An Evaluation of FORPLAN from an Operations Research Perspective:Discussion Paper

Daniel I. Navon[1]

Abstract.--A framework for evaluating computerized systems for public land management planning is used to review and extend Bare and Field's analysis. The linear programming (LP) system FORPLAN is a powerful and appropriate tool for public land management planning. However, thorough validation of the FORPLAN models and extensive sensitivity analysis of the LP solutions are essential to determine the reliability of the computerized analysis. Adequate and cost-effective sensitivity analysis and validation require FORPLAN LP models which are smaller and simpler than those typically used in the current cycle of planning. A hierarchical planning strategy for using FORPLAN, which is consistent with simpler and smaller FORPLAN models, is sketched and evaluated.

Bare and Field observe that in 1979, when FORPLAN was chosen as the system for elaborating land management plans for all National Forests, no other system met the Forest Service needs:

> to satisfy the optimization requirements of the National Forest Management Act;
>
> to control and to promote uniformity in planning among the National Forests;
>
> to use an accepted analytical technique which had been successfully used in forestry.

They argue that using FORPLAN to allocate land and to schedule management simultaneously may have "raised LP to its level of incompetence," and that today the FORPLAN system produces:

> models which are too large, too poorly understood, and too costly to be of much value;
>
> models which do not adequately address the linkages among strategic, tactical and operational planning, and
>
> models which do not "recognize or comfortably fit the real process of making decisions on the National Forests."

Based on an extensive review of recent developments in operations research, Bare and Field conclude that separate models tailored to the strategic, tactical, and operational phases of planning hold the greatest promise for effective planning. They speculate that a misunderstanding of the planning problem may be the root problem and recommend that before any changes in analytical techniques are considered, "the relationship between planning and decision making in the Forest Service must be completely and satisfactorily resolved." They conclude that only then can a task force of decision makers, planners and analysts specify the "analytical support necessary," and can "issue bids for the purchase and installation of a "planning support system."

The questions posed and answered by Bare and Field are relevant. An operations research perspective requires an examination of both the structure of a system, and of the way it will be or was used. Bare and Field quickly abandon their self imposed restraint "merely to examine the mathematical apparatus" and they review the way FORPLAN was used by Forest Service land management planners. Their assessment of the implications of LP for forest management planning is incisive, their discussion of the questions posed is full of insights and wisdom, and their review of current developments in operations research applications to forest planning is a valuable guide to available tools. Their answers are plausible, and their conclusions, although severely critical, are mostly reasonable and constructive; but their arguments are not entirely convincing.

There are several weaknesses in their analysis: 1. They do not fully trace the consequences of violating the fundamental assumptions of LP; 2. Some key questions about implementation have gone unanswered; 3. Throughout their discussion they do not clearly distinguish between the problems and failures caused by the structure of FORPLAN and those attributable to the way FORPLAN was used.

We shall attempt to correct these minor deficiencies, and we shall do it in way which may be useful to those who in the future will be responsible for selecting, developing, and guiding the use of operations research techniques to plan the management of National Forests.

We shall present a simple but comprehensive framework for evaluating mathematical programming and simulation systems, use it to review and complete the evaluation of FORPLAN made by Bare and Field, and finally we shall show how this framework can also be used to evaluate a hierarchical planning strategy for implementing FORPLAN more effectively.

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EVALUATION FRAMEWORK

The "framework" is simply three sets of criteria which address the questions: Is the computerized system SOUND--free of logical and programming errors? Is it OPERATIONAL--can it be, or has it been, used correctly and cost-effectively in planning? Is it RELEVANT--does it, or can it, meet institutional requirements and information needs? Note that this evaluation framework can be used either before, or after, a system has been implemented. The inspiration for this framework is clearly traceable to Bare and Field; however, it will become quickly apparent that it is sufficiently different from the three questions they posed to absolve them of all responsibility for its shortcomings.

Is the Computerized System SOUND?

Three principal criteria must be satisfied: is the system free of logical errors, are computer programs reliable, and can the system be used to generate models which are an acceptable representation of reality?

System Logic

For simulation models of the level of complexity required in forest planning, checking the logic rigorously is likely to be impossible or at the very least impractical. But for mathematical programming systems, the logic can be checked rigorously if adequate documentation is provided. It is essential this be done, and that errors be corrected, before the system can pass muster.

Program Quality and Management

Regardless of the level of competence of the programmers, some errors will remain in the large and complex programs typically used in land management planning (LMP). Programs must be designed to ease debugging, and to limit the consequences of errors caused by bugs discovered only after the analysis is under way, or is completed. Updates and extensions of the program rapidly compound the probability of serious errors, eventually requiring rewriting the code from scratch if reliability is critical. How the computer programs have been, and are, managed is a key factor in assessing the soundness of the system.

Representative Models

Computerized systems used in LMP result necessarily in simplified representations of reality. Simulation systems allow the designers great freedom in choosing the level of realism. The limit on achieving the most desirable level of realism in a simulation model is the cost of writing, and running, the simulation programs. This cost can be very high. Mathematical programming systems have additional restrictions which reflect their structure, and the algorithms available to solve them. For example, LP requires using only production processes which are "linear and independent." Linearity here means that outputs must be directly proportional to inputs, and that both inputs and outputs must be divisible into small increments, e.g. acres, dollars, recreation visitor days, acre feet of water, thousand board feet of timber. Note that a bridge or visitors' center is not divisible into small increments, and therefore cannot be represented in an LP. Independence requires that each production process be unaffected by the selection of any other process, even on adjacent areas. The implications of the restrictions imposed by mathematical programming must be worked out and evaluated to establish whether an acceptable level of realism can be reached. Finally, the data requirements of the system must be established, and assessed against the data which is likely to be available to intended users. The range of reliability of the of data is also very important. If some of the data required to run the system are accurate and others are less so, the reliability of the LP solution may be indeterminate, and the solution may confuse rather than inform.

Is the System Operational?

Can the System be run correctly and cost-effectively in operational situations? System designers tend to be optimistic about the capabilities of the hardware and software required by their brain children. They also tend to assume that users are, or will become, their equal in sophistication. So, we must now add: given the institutional setting, is the system likely to be used correctly and economically? The implications of the system's inherent characteristics must be re-examined in the operational context.

Is the System Relevant?

Does the system address the information needs, and is it consistent with institutional requirements? Information needs and institutional requirements are seldom well defined and, in the process of planning, they will be revised--perhaps radically. The system must have the flexibility to accommodate changes in needs and requirements. The capabilities of the system must be matched against initial needs and requirements, and inconsistencies identified (e.g. a system may be incapable of producing solutions which are both site specific, and globally optimum). The system must be usable in a way which will resolve such conflicts, or which will lead to acceptable compromises. This may require the elaboration of "planning strategies" for implementing the system. The validity of the analysis conducted with a technically sound system may well depend on the design of such planning trategies. Several planning strategies for implementing FORPLAN are discussed below.

The three sets of criteria are closely related. For xample the assumptions underlying a system determine its oundness, but they will also affect its ease and cost of peration, and the extent to which the system addresses nformation needs, and perhaps even institutional equirements. In FORPLAN, linearity and certainty ssumptions lead to acceptable soundness only if extensive ensitivity analysis is conducted when the system is used. This is both costly and difficult, thereby affecting the perational rating. If the sensitivity analysis shows that the olution is vulnerable to departures from linearity and ertainty, some information needs may not be adequately net.

The evaluation of a system cannot proceed simply by pplying each set of criteria serially. Interactions must also e considered. Grouping the criteria is simply a way of rganizing the immensely complex task of assessing the otential of computerized systems. It also brings into harper focus the source of the problem: Is it the structure f the computerized system? Is it the way the system is--or will have to be--implemented? Is it the way information needs and organizational requirements are defined? Focusing on the source of the problem will help change the design or the implementation strategy of the system, and may help in finding a better system.

FORPLAN REVISITED

Let us now use this framework to review and complete he evaluation of FORPLAN presented by Bare and Field.

Is the Computerized System Sound?

Bare and Field limit their assessment of the soundness f the FORPLAN system to a discussion of the implications f the assumptions of LP for modeling management on National Forests. They propose that linearity and ndependence can be dealt with by "careful formulation of he model and cautious interpretation of the solution..." They note that LP is "deterministic"--that random variation n the data cannot be represented--and they suggest piecewise linear representation as a possible albeit xpensive fix. Bare and Field conclude that these haracteristics of LP do not pose insurmountable difficulties, and they proceed to evaluate FORPLAN, trictly based on the results of operational runs.

Bare and Field take for granted the conceptual oundness of the system. Because there has been no efereed publication on FORPLAN, an examination of the tructure of the system is in order. If effort, talent, and professional integrity could assure the soundness of omputerized systems, we could assume that FORPLAN were sound, and could dispense with further discussion on his subject. Because this is seldom the case, an examination s required, if only to identify those peculiarities of the ystem which users must know to run FORPLAN correctly, and which decision makers and analysts must understand to interpret the printout.

System Logic

Bare and Field infer from some "illogical results" obtained by Region 8 National Forests, that there may be something wrong with the model. They may be right. Yet, because they acknowledge that the complexity of the LPs rendered them opaque to analysis, we will never know unless the mathematical structure is systematically verified. This has been done by the developers, and a Mathematical Programmer's Guide for Version 1 has been published (Johnson 1986). A similar Guide for Version 2 is in preparation. Based on heroic--and only occasionally successful--efforts to work through the Version 1 Guide, we can only speculate that few will be able to gain useful insights into the mathematical structure of FORPLAN by referring to these Guides. The notation is cruelly complex, requiring infinite patience and stamina of those not blessed with a photographic memory. This suggests that even experienced analysts may not be able to deduce logically the relationships among the growing number of options available. Assuming there are no errors in logic, it will become increasingly unlikely that logical errors can be detected analytically if proposed extensions to the system are made. Detecting errors in logic by running sample problems is not an adequate substitute for rigorous analysis of the mathematical model. It is not likely to catch all the errors, and it is not cost effective.

There are other imperative reasons for presenting the model logic rigorously and in a way accessible to analysts. First, some available options--falling demand and Aggregate Emphasis/Coordinated Allocation Scheduling among others--require a clear understanding of the mathematical structure of the model to avoid potentially serious errors in formulating models and interpreting the solutions. Second, to permit an effective public review of National Forest land management plans, interested parties must be able to gain a thorough understanding of the analytical procedures used without unreasonable effort. The current Mathematical Programmer's Guide is comprehensive but so difficult to follow that its usefulness is questionable.

Computer Program Quality and Management

The probability of undetected programming errors is widely believed to increase exponentially as the number of modifications made to large computer programs increases. FORPLAN Version 2 has undergone twelve major updates at this writing. The implications for the FORPLAN matrix generator and report writer would be chilling were it not for the care and energy and expense which has been devoted to hunting and exterminating "bugs." Some legitimate concern about the existence of bugs must remain, requiring users to validate the FORPLAN solutions with great care. The implication is that FORPLAN models must be kept simple enough to make this validation practical and affordable. A complete rewriting of the programs also may be appropriate to ease debugging.

Representative Models

Bare and Field wisely point out that computerized systems are not expected to produce "perfect model(s) of the real world," and that the greatest danger is that the system "is working less perfectly than the modeler (or client) thinks it is." This danger is very great in FORPLAN. Analysts are known to have a very low resistance to using options, especially when their use has been made easy by partially automating the data input. Analysts are likely to forget to keep on assessing the implications of the simplifying assumptions as they elaborate their models. Acceptable departures from reality in the early stages of model construction may rapidly become untenable as increasingly complex modeling options are exercised. For example, independence and linearity of production processes is quite a reasonable assumption when timber is the only output represented in the LP. In FORPLAN, linearity means that inputs and outputs are directly proportional (linear) to the number of acres managed with a prescription. Independence means that the inputs and outputs per acre of a prescription are unaffected by the choice of prescription for other acres, even if these acres are nearby or adjacent. These assumptions of independence and linearity become questionable when dispersed recreation--measured in Recreation Visitor Days per acre--is added to timber harvested; and these assumptions become quite unrealistic when tons of sediment, or acre feet of water, per acre are also added. Sedimentation rates, water flow, and recreation capacity are affected by vegetation manipulation on neighboring acres--which violates the independence assumption-- and are known not to be proportional to the number of acres managed--which violates the linearity assumption.

A fundamental question must be raised at this point: Is the relation between decision variables such as acres managed and recreation capacity--or sedimentation--sufficiently well known to describe it with the linear equations of LP? If knowledge is not sufficient, the imperative to promote a balanced analysis by including all quantifiable inputs and outputs in the LP must be resisted. For, to quote Holling and Dantzig--the father of LP--on Determining Optimal Policies for Ecosystems: "To develop an analysis which implicitly or explicitly presumes sufficient knowledge is ... to guarantee management policies that become more the source of the problem than the source of the solution" (Holling 1986). The inclusion of recreation, water, and sediment outputs in FORPLAN LPs may be based on presumed rather than actual knowledge.

The allocation/scheduling option has been proposed by the developers of FORPLAN as a logically sound way of dealing with the non-linearity and non-independence of some production processes such as recreation capacity, road construction, sedimentation and waterflow (Johnson 1986). But this would transform FORPLAN into a Mixed Integer Linear Program, and the typical forest-wide model could be solved--if at all--only at prohibitive expense. If FORPLAN is to be judged sound, the practical limitations on the use of its modeling options must be more clearly explained.

Similar limitations on the data used in FORPLAN are needed to preserve the soundness of the system. Because variability in the quality of the data cannot be explicitly represented, the quality of the data must be reasonably uniform. If it is not, the possibility that the results of the analysis are no better than the weakest data used in the model cannot be ruled out. Then the claims that LP can assure efficient allocation and consistency with Forest Service policies may not be sustainable when some of the data included in the FORPLAN LP are very soft. The implications are far reaching for a system which purports to model events into the distant future. To the inherent variability of ecological and economic data, the uncertainty of the future must be added. Thus optimizing, or constraining, linear combinations of outputs measured with greatly different accuracy over several decades casts a long shadow on the soundness of the system--a shadow which may be impossible to remove by the "careful interpretation of the solution" proposed by Bare and Field.

Is the Computerized System Operational?

In examining the question "Did FORPLAN work?" Bare and Field address mostly the difficulties encountered in solving FORPLAN LPs, and they identify size and density of non-zero elements as the principal culprits. They review the efforts to resolve these difficulties reported by Kent (1986) and conclude that "FORPLAN is taxing the LP state-of-the art" and that this should "be an incentive to consider alternative cures of the disease rather than (applying) more band aids."

The solution of large LPs has long been known to require "tuning" the algorithm parameters to the peculiarities of the model structure. This apparently has been done very successfully for Version 1 and 2 FORPLAN models (Kent 1986). Infeasibility of FORPLAN LPs, however, will remain a problem as long as large and complex models are formulated because errors in formulation cannot be entirely avoided in such problems. The greater the complexity and size of the model, the longer and costlier the process of finding and correcting these errors in formulation.

The cost of solving very large FORPLAN LPs is also noted by Bare and Field. It is not likely to fall in the near future. Expectations of substantial economies raised by the development of the Karmakar algorithm have not yet been realized; therefore, the prospects for FORPLAN LPs are not encouraging (Adler 1986). Large FORPLAN LPs are likely to remain expensive into the near future, and the prospects for solving FORPLAN models requiring a mixed integer algorithm are very dim except for models a fraction the size of typical forest-wide models. It is doubtful that site specific prescriptions can be included in the FORPLAN models without having recourse to mixed integer programming algorithms or special heuristic procedures. In either case, if the FORPLAN models are large, the cost and the difficulties in getting acceptable solutions probably will lefeat all but the most dedicated, and generously funded, nalysts.

Comprehensive documentation is now available for /ersion 1, and soon will be available for Version 2. It is xiomatic that the documentation of large computerized ystems is at best inadequate, and remains largely unread if iot totally ignored. Nevertheless, we do need to be oncerned here with FORPLAN documentation. The omplexity of the system precludes a largely oral ransmission of knowledge, and the large number and imited tenure of the intended users group insure that the locumentation will be pivotal in assuring the correct and fficient use of the system. In documenting computerized ystems, comprehensiveness while essential is not sufficient. 'he documentation must invite perusal by users, it must be nade user friendly if the chaotic rule of Murphy's laws is to e avoided. The FORPLAN Mathematical Programmer's ind User's Guides need to be revised to make them more nviting, or at least more accessible to users.

A complete assessment of whether FORPLAN is perational must await a thorough evaluation of the xperiences of forest and regional analysts. However, the haracteristics of the computerized system and of the locumentation do provide clear indications of the potential roblems discussed above.

Is the Computerized System Relevant?

Does it address the information needs and institutional equirements which finally emerged from this first round of lanning. These needs and requirements have been dentified earlier in this symposium.

Bare and Field's questions: "FORPLAN as a Model: Vas it Right?" and "FORPLAN as a planning Tool: Was it Jsed?" both address the issue of relevance in a roundabout vay. They are concerned that some models produced esults which are "often illogical and in some cases illegal." from which they conclude that "If the model cannot avoid hem without arbitrary constraints, then something is either vrong with the model or the policies that are being iolated." The cases they cite, however, clearly suggest that he FORPLAN model confronted the planners with nconsistencies between economic optimization and dministrative priorities and policies (to maintain stable udget and harvest levels). It appears that the FORPLAN nodel, far from being invalid, may have been teaching the nalysts a lesson in forest economics, and properly may be redited with having forced analysts to reconsider notions f dubious validity.

By "used" Bare and Field mean: Was FORPLAN used successfully in developing and supporting valid forest lanning decisions that would not otherwise have ccurred?" They conclude from discussions with users and lecision makers that insights useful in decisionmaking--ather than answers--were gained. However, they report hat the size and complexity of the FORPLAN models did iot allow a rigorous sensitivity analysis of results--"except in he development of the preferred alternative."

The cases, interviews, and observations presented by Bare and Field provide an impressionistic basis for assessing the extent to which FORPLAN has addressed information needs and institutional requirements. Their analysis needs to be brought into sharper focus to derive guidelines for future planning.

The primary institutional requirement, that is to develop forest-wide plans consistent with management guidelines and based on an optimization procedure, has been satisfied for nearly all the National Forests. The remaining Forests are completing their plans with FORPLAN. Another institutional requirement also has been addressed with considerable success: to promote an integration of all the functional activities in the planning process. These are considerable achievements. However, when the attempt to integrate functional activities has been carried out by capturing all quantifiable outputs in the optimization process and in the constraint structure, it has created potentially serious problems. The size and the structure of the model has been greatly complicated in the attempt, often futile, to find linear approximations for production processes which are intrinsically non-linear, or for production processes which are still beyond the state of knowledge. The number of resource strata have been increased to represent differential conditions associated with the additional outputs. Prescriptions have been added to model the management of these outputs. The consequences may have been bloated models, and solutions of indeterminate reliability.

The Forest Service information needs were defined by lists of inputs and outputs, and indirectly by procedural planning requirements: analysis of the management situation, benchmark analysis, development of a range of alternatives. Strongly voiced but vague concerns for linkages with Program Planning, Program Development and Budgeting, and Project Planning also had some influence in defining information needs. Much, and on some National Forests most, of this information was extracted or derived from FORPLAN solutions. Is this information a bounty? Yes, but only if the data are reliable! There may be the rub. The statistical reliability of FORPLAN solutions is indeterminate. The data used in the models are known to vary greatly in precision. Reliability has been further compromised whenever the assumptions of linearity and independence have been stretched for the sake of capturing many functional activities in the FORPLAN LP models. We must also admit the high probability of errors in loading the data in the computer programs, especially in large and complex models, and the possibility of programming bugs and errors in system logic. Finally, we must recall that the uncertainty of the future has not been factored into the computation of the LP solutions. The reliability of the FORPLAN solutions to comprehensive, forest-wide models will therefore always be at best questionable.

The current incarnation of FORPLAN Version 2 (Release 12) is very probably free of logical errors, and of serious programming errors. Future extensions to the matrix generator and report writer programs may pose problems. The documentation while comprehensive is inadequate to check the logic and programming. The FORPLAN system is operational to the extent that it has been used successfully in the preparation of most National Forest land management plans. However, the cost of running FORPLAN may have been excessively high, and the system too complex to master for many, perhaps most, forest level planners. The evidence pointing to the high cost and excessive complexity of FORPLAN discussed by Bare and Field--and that available to this reviewer--is admittedly anecdotal and fragmentary. But it reflects a concern often expressed by Forest personnel. A final determination of the seriousness of this concern must await a carefully designed survey of actual experiences by Forest level planners and line officers. While FORPLAN has addressed Forest Service institutional requirements, there are questions about the adequacy and reliability of the information computed with the system when large, comprehensive forest-wide models have been used. The assumptions inherent to linear programming may have been stretched beyond reason, the LP models may not have been adequately validated, and the solutions may not have been tested with the extensive sensitivity analysis required in applications of LP to ecosystem management.

Should we then use FORPLAN simply as an accounting device? Return to using simulation, or better yet, regress to the proverbial back of the envelope and the Austrian Formula? The excellent survey of available approaches given by Bare and Field does not hold the promise of attractive alternatives to FORPLAN. Besides, there are planning strategies which promise more reliable FORPLAN solutions, and lower costs, but at a price: giving up the impossible dream of comprehensive, site specific forest-wide optimization within the LP, and getting down to simpler models and more uniformly reliable data in the LPs.

PLANNING STRATEGIES

Bare and Field suggest that conducting the analysis of land allocation and of management scheduling separately might "be a more logical and understandable approach" which, while not guaranteeing "optimality...may well produce more understandable results which can be implemented in the real world." It is very doubtful that such a strategy would provide adequate estimates of the Allowable Sale Quantity (ASQ) on national forests where timber is one of the major outputs.

A similar strategy based on a multistage approach was used successfully on the Shoshone NF (Mitchell 1986). However, the Shoshone National Forest is not a significant timber Forest. Another strategy, using multiple smaller FORPLAN models which address critical issues such as endangered species, size of cuts, and roadless areas, already has been used successfully in Region 5 (Barber 1986). With both of these strategies, costs were substantially reduced, and there is reason to believe that the reliability of the FORPLAN solutions was greater than it would have been if a comprehensive approach had been used. Smaller, simpler models made a thorough search for errors practical, helped the validation of the solution against experience, did not stretch the LP assumptions beyond reason, and most importantly made a systematic and extensive sensitivity analysis practical, economical, and informative.

A third strategy is an extension of models designed specifically for planning the management of wildlands (Navon 1976, 1986). This strategy has been tested on a large private forest enterprise in Chile (Weintraub 1986), and it reflects recently conducted tests of a prototype method for systematically reducing the size of FORPLAN models (Navon et al. 1986). This hierarchical strategy makes a sharp distinction between "strategic" and "tactical" planning.

Strategic planning addresses policies (timber harvesting level, land allocation) and issues and concerns (protection of endangered species, allowable sale quantity, use of pesticides/herbicides, designation of roadless areas). Tactical planning determines how policies will be carried out, and how issues and concerns will be resolved by scheduled and site specific management activities.

Strategic planning is properly conducted at the forest-wide level. It must extend over at least a full rotation, a time span sufficient to assess the long range consequences of policies and of decisions driven by issues and concerns. The sheer scope of the task suggests that the resources be roughly stratified, the management options kept few, and the production processes defined only by critical inputs and outputs. This level of resolution is consistent with the type of decisions taken by the Forest Supervisor, and is also consistent with most of the information requirements of the Forest Plan.

Tactical planning is bounded by the decisions of strategic planning and is most effectively conducted at the District, the lowest level responsible for on the ground management. The time span can now be more limited, say to the horizon of program budgeting. Only the management options available in the next few years need be considered in detail, but production processes must now be defined in sufficient detail to permit adequate accounting of on the ground management costs and of accomplishments. Note that the timber sale schedule required for the Forest Plan is clearly a tactical planning objective. Therefore, the Forest Plan requires both strategic and tactical planning.

Let us sketch how such a hierarchical strategy might be used with FORPLAN to prepare and implement the Forest Plan, and note how it differs from the current strategy of attempting to do site specific, comprehensive, allocation and scheduling for the entire forest in a single FORPLAN LP model.

Step 1.--Build a small and "crude" forest-wide FORPLAN model for strategic planning, with resource strata acreages, prescriptions, and plausible ranges for critical inputs and outputs provided by each District. All the data required for such a model are available on Forests which have run FORPLAN models. The current level of resolution does, however, need to be lowered to conform to the thrust of strategic planning: policies, issues and concerns. Analysis areas must be combined, the number and scheduling choices of the prescriptions reduced, production processes represented only by dollars, timber, other critical inputs and outputs for which reliable data is available, and by proxy indices for outputs for which reliable data are not available. The objective function and constraints must also be specified with explicit consideration for the reliability of the data.

Step 2.--Conduct an analysis of policies and issues with the Strategic forest-wide FORPLAN model: compute

Benchmarks and the set of Alternatives from which a Preferred Alternative will be selected. FORPLAN LP model solutions will have to be complemented with estimates of inputs and outputs not included in the LP. The FORPLAN LP solutions may have to be revised based on professional judgment, or recomputed after prescriptions or constraints have been modified to accommodate the production of the outputs not included in the LP. This process, while not optimal in the technical sense, promises a level of efficiency consistent with the state of knowledge and data available.

To insure that each Alternative can be implemented, it must be validated by every District. This can be done by allocating the solution of the forest-wide model among the Districts. FORPLAN report options are already available to do this. Changes requested by Districts may occasionally require solving additional forest-wide LP models. Iterating between the District and Forest can be minimized by imposing constraints on some District inputs and outputs in the FORPLAN forest-wide LP model, and in the computation of the levels of the outputs not included in the LP model.

Step 3.--Once the Preferred Alternative has been selected, each District can conduct a site specific analysis of management options, at a level of detail consistent with its information needs and its planning resources. The data available on most National Forests may provide an adequate level of resolution. Data resolution can be refined selectively to meet specific management needs, e.g. to develop recreation areas, to plan timber sales for the next 5 or 10 years, and to manage the roads and trails network. The analysis can be conducted in part, or largely, within a FORPLAN LP model. This model still would be very much smaller than current forest-wide models. It would span fewer years and many fewer acres. Management options for the next decade are severely limited by past commitments, and by the first hand knowledge of the District staffs of what is practical. Therefore, detailed prescriptions will be required only for a fraction of the District acreage blanketed with prescriptions. Furthermore, prescriptions need reflect only the guidelines imposed by the Preferred Alternative. With these small District models, the use of FORPLAN options for representing site specific management activities (road networks, Coordinated Allocation Zone, etc.) could be practical and cost-effective.

How sound, operational, and relevant would such a planning strategy be if both the forest-wide and the District models were prepared with FORPLAN? How much of an improvement could it bring to forest-wide planning and to Forest Plan implementation?

Sound? Whatever logic and programming errors remain in FORPLAN still would be a problem. However, with simpler and smaller models it would be easier to recognize and track down pathological system behavior and aberrant results. Assumptions would not be stretched as taut as they often are now. Policies, issues, and concerns could be effectively analyzed with a "what-if" process, thus eliminating the necessity of including all the inputs and outputs relevant to multiple use management in the same LP. Besides, with simpler and smaller models, a few of the non-linear processes now could be correctly represented in the LP by special integer variables, and models still could be solved at reasonable cost. The certainty assumption would not cast as long a shadow, because with small models, what-if runs could be used to test the robustness of solutions over ranges of future natural and economic events.

Operational? The cost of processing and solving many small LPs still would be substantial, but would be very probably much lower than for processing fewer larger LPs. Savings in generating and interpreting solutions, and particularly in debugging models, would be large and likely. Automated data processing costs also may be reduced: the simpler structure of both the forest-wide and the District models would not tax the expertise of analysts and planners as much. Fewer runs would have to be redone. Substantial reductions in solution costs also could be realized using techniques for shrinking FORPLAN models currently under development (Navon 1986). These techniques work most effectively on models whose structure is only moderately complex. As experience is gained, models may be sufficiently reduced in size and complexity to solve them on microcomputers, greatly reducing turn-around time and costs. Complementing the forest-wide model solutions to factor in critical inputs and outputs not explicitly represented in the LP could prove to be difficult and costly, but is not likely to swamp the savings from reducing the size and complexity of the FORPLAN LP models.

Relevant to institutional Requirements? The forest-wide and District models would still promote the integration of all the multiple uses of the forest in the planning process. Explicit representation in the LPs of every use is not necessary, it can even be counterproductive. When reliable information is not available on some uses, or when management for these uses cannot be plausibly approximated by linear production processes, including these uses in the LP gives only an illusion of multiple use planning. Substituting a greater measure of professional judgment for computerized analysis in the elaboration of Benchmarks and Alternatives is likely to strengthen planning. But would the optimality requirement of the NFMA Regulations be satisfied? At least as well as with large comprehensive models, and in all probability much better. The objective functions optimized in comprehensive models are a heroic attempt to do an impossible task. The level of optimization achieved may well be indeterminate, because the reliability of the data in the FORPLAN solutions are unknown. At least with smaller and simpler models, the reliability of the solutions could be established and a measure of efficiency could be legitimately claimed. Therefore, the institutional objectives to promote integrated resource planning and to optimize net social benefits may be better served by less comprehensive models.

Relevant to information needs? Current FORPLAN models tend to overwhelm the Forest Supervisor with detailed information and yet do not provide District Rangers with sufficiently detailed, site specific data for implementation. With a hierarchical strategy, each model would be focused on a single level of decision making. Each model would provide information in terms directly relevant to the decisions over which the Forest Supervisor and the District Ranger have primary responsibility and control: allowable sales quantity, roadless area designation, roads and trails development, etc., for the Forest Supervisor; use permit and timber sales administration, project planning, etc., for the District Ranger. The stakes of Supervisors and District Rangers in land management planning would be increased, and, if so inclined, these line officers could fully understand and gain control of the FORPLAN models.

A hierarchical strategy is not without costs. Line officers, already burdened with heavy responsibilities, must participate actively in a hierarchical planning process. Incentives must be found to induce planners to keep the FORPLAN models small and simple. Hierarchical planning only makes such models possible. Some loss in optimality will be incurred. The losses in present net value are not likely to be statistically significant given the softness of the economic data available for forest-wide planning. Losses in the timber allowable sales quantity will occur and may pose a more serious problem. Statistical analyses will be needed to determine their significance. Preliminary results suggest that very substantial reductions in model size may be achievable for reductions in allowable sales quantity which are probably not statistically significant (Navon et al. 1986).

Long before the next cycle of forest-wide planning begins, some Forest Plans will have to be revised. Some alternative to forest-wide, comprehensive, site specific allocation and scheduling is needed to make FORPLAN a more reliable and cost-effective planning system. A promising strategy is to use separate FORPLAN models to address the information needs of the Forest Supervisor and District Rangers. The proposed hierarchical strategy is very sketchy, and its evaluation is admittedly somewhat superficial. Additional work is needed to establish its usefulness. In particular, the linkage between the forest-wide and the District models requires further elaboration and scrutiny, and a rigorous statistical analysis of the consequences of reducing data resolution in the forest-wide model is needed. The objective here is only to start a discussion of ways and means to improve the cost-effective use of FORPLAN.

A complete evaluation of FORPLAN must await a survey of the experiences of planners and decision makers on National Forests. Nevertheless, the structure of the computerized system, its documentation, and the fragmentary reports on its field use, do point to problems and to opportunities for improving the way FORPLAN can be used to elaborate implementable forest-wide alternatives. A hierarchical planning strategy holds great promise for grasping these opportunities.

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FORPLAN: Does It Meet the Statutory Requirements?

Charles F. Wilkinson[1]

Although we are in a transition stage, the domination of timber harvesting in the National Forest System is ending. Within roughly 8 to 10 years, the national allowable cut will begin to drop steadily but slowly. Within roughly 15 to 20 years, the cut will become stable at a substantially lower level than it is now, probably 20-25% below the current figure of 11 billion board feet. Then the phrase multiple use, may still be in the law; but it will have been replaced in common discourse and very likely in codified law also by a concept recently coined by [former] Arizona Governor Bruce Babbitt. His phrase for the new doctrine of land management on both Forest Service and BLM lands is "public use."

The national forests are run by a blend of economics, recreation, wildlife biology, power politics, minerals policy, ecology, silviculture, local color, wilderness philosophy, hydrology, law, romanticism, and the institutional personality of what is probably the greatest and most interesting resource agency in the world. Such diverse sources have defined the almost incomprehensibly large package of benefits received from these lands.

Several trends suggest new directions in forest policy. A growing number of states are opposing Forest Service timber practices. The curricula in the forestry schools over the past 15 years has broadened; many of those schools have been redesignated as natural resource colleges. Western guides and packers are becoming more hostile toward Forest Service programs. Public awareness of the interconnectedness of all resources is increasing, especially the way most extractive development affects water. American Indians are becoming more involved in Forest Service disputes. The State of Montana concluded in it's 1986 water quality report that "accelerated road building and timber harvest on U.S. National Forest lands now pose the single greatest threat to aquatic life in Montana." More small land owners once cherished but are now angered by the location of their summer homes on land bordering the National Forests. The public is participating in National Forest policy more. The population in the American West is increasing, many of the new arrivals are attracted to the public lands. The State of Colorado concluded this year that the National Forests in Colorado produce $4 billion in recreational benefits. There is a growing perception among observers that the rationale for the high level of subsidized below-cost sales lacks integrity. The young people hired by the Forest Service during the past decade have differing philosophies. There is a new appreciation for pacific salmon and steelhead resources and the effects that logging and roading can have on them.

Several sketches can be presented fairly that show very different things. They include: (1) the widely held idea that we need to extend a hand to residents of small timber-dependent communities; (2) a possible upturn in housing starts; (3) the potential of a greatly increased demand for American wood products in third world nations; (4) the success of [Oregon Senator] Mark Hatfield, as able and visionary a person as there is today in public policy anywhere, in using the appropriations process to raise the cut in Region 6 from 4.6 billion board feet to 5.2 billion board feet during this fiscal year.

Those and many other such examples could be given. But the first set of trends gives a truer picture, not of all future policy, but of irresistible forces that will be accommodated by Forest policy and that will cause a gradual nondisruptive decline in the allowable cut.

Last year, Governor Babbitt, in an address to the annual convention of the Sierra Club in San Francisco, noted that in 1903, President Theodore Roosevelt met with John Muir in Yosemite National Park to talk about the preservation of wild land. Babbitt, often critical of the current administration's natural resources policy, concluded his talk by hoping that the time would again come when the Presidents of the Sierra Club and of the United States would meet in Yosemite. But the heart of his talk was,

> "We need a new western land ethic for nonwilderness. The old concept of multiple use no longer fits the reality of the new West. It must be replaced by a concept of public use. From this day on, we must recognize the new reality that the highest and best, most productive use of western public land will usually be for public purposes, watershed, wildlife, and recreation. The move to public use of the climax of a long historical process. The Homestead Act of 1862 recognized that public lands should be used to facilitate settlement and development. Seventy years later having served that purpose, the public domain was closed to homesteading. The next phase in the evolution of public lands was private resource development. The Mineral Entry Act, the Timber Entry Act, and the Reclamation Act of 1902, put the public lands up for mining, grazing, logging, and water development. We are now at the threshold of the final stage in the evolution of public lands policy. The great urban centers of the West are filled with citizens who yearn for solitude, for camping facilities, for a blank spot on the map, for a place to teach a son or daughter to hunt, fish, or simply survive and enjoy. The time is at hand to go beyond multiple use. Mining entry must be regulated. Timber cutting must be honestly subordinated to watershed and wildlife value. And grazing must be subordinated to regeneration and restoration of grassland. Many of the Forest Service and BLM plans now being circulated ignore the primacy of public values. It is now time

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> to replace neutral concepts of multiple use with a statutory mandate that public lands are to be administered primarily for public purposes."

This concept is likely to shape public debate in this field over the course of our careers. Conceptualizations of policy have always mattered, whether it was manifest destiny, all the way through the sagebrush rebellion, including multiple use. I expect that public use could become in that category. It's important, though, to recognize what Babbitt did not say. He recognized and would affirmatively advocate that extractive uses such as timber harvesting, mining, and grazing must continue. But they should be as he put it, "honestly subordinated to public uses." Implicit in his formulation are two ideas about multiple use. First, that multiple use, perhaps unlike sustained yield, has little substantive content. It doesn't tell you which choices should be made. Second, multiple use has tended to produce, depending upon the region, domination by timber grazing, mining, and water development interests. Public use would not and should not erase those uses. But it would produce them. The reduction in allowable cut that I think will come is an example of public use. A draw down of 25% of the total cut would greatly ameliorate the key stresses that we now see on public uses.

How is the Forest Service reacting to these pressures already in place that may lead toward future recognition of public use? The returns are mixed. The first is a decision handed down by the Ninth Circuit Court of Appeals in San Francisco earlier this year. The Forest Service manages Lake Shasta in northern California. It's a major recreational resource and has had houseboats on it in the past. The Great American Houseboat Company began to sell time-share units on houseboats, making them kind of floating condos. The Forest Service, realizing that this would greatly increase the user days on the lake, combated the sure overcrowding by adopting a permit system outlawing most time-share ownerships in houseboats on Lake Shasta. The Forest Service had no specific authority to do that in the statutes. The Appellate Court upheld the Forest Service's permitting system. Ruling that the agency's power to regulate "occupancy and use" within the forests, tracing back to the 1897 Organic Act, was broad enough to encompass the houseboat regulation for which again there was no express support in any statute.

In a second example, the agency has acted in an opposite way. The Hard Rock Mining Law of 1872, perhaps the most outmoded of any public lands statute enforced today, allows hard rock miners the right to enter most public lands, and if they make a strike, to receive title not just to the minerals but to the overlaying 20 acres of land also. What that Act did was to zone the public lands for mining. The previously unrestricted autonomy of miners has been cut back in many ways partly because of the many environmental impacts from poor mining practices. However, the Forest Service, in many cases, is refusing to take the tough steps. If you talk to Forest Service mining officials in the field, you find that their marching orders are that they may "regulate" miners, but they cannot deny to them the right to mine, even if miners refuse to comply with all necessary Forest Service requirements.

As Professor John Leshy of Arizona State University Law School concludes in his upcoming book on the Hard Rock Mining Act, the Forest Service is far too tender toward industry on this issue. There is no absolute right to mine. The Forest Service ought to assert maximum management authority while exercising it fairly and reasonably over this major class of forest users.

Third, the Forest Service has made what seems to be a truly unfortunate set of decisions on key issues relating to water pollution. The so called "Go-Road case" was handed down last year, and then a slightly amended opinion was reissued this last summer. The Ninth Circuit Court held that proposed logging and the Go-Road itself on national forest lands failed to meet California water quality standards to protect against erosion.

The Forest Service argued that it required loggers to follow so called best management practices (BMPs), such as requiring buffer strips and setting soil types in gradients where logging may not occur. But the Ninth Circuit Court said that BMPs are only a means to an end, and that loggers must meet California's substantive standards such as its requirement that turbidity cannot rise more than 20% above natural turbidity when the additional turbidity is caused by development activities. The state turbidity standard, the courts said, is an end, not a means, and it must be complied with. A great conservation agency, especially one aware of the fragility of anadromous fish runs, and especially an agency recently chastened at Mapleton, should have applauded that decision as a key element in our continuing and frustrating struggle to find reasonable ways to reduce erosion from non-point source pollution. Instead, the Agency recently went to EPA and sought to have the Go-Road ruling administratively overturned.

In 5 to 10 years, maybe sooner, the kinds of restrictions that California, and Idaho, and Montana, and others are enforcing for erosion will be accepted as a matter of course, in my view. Our rivers require those kinds of standards, and so do the animals in them. But instead of being in the vanguard of an irresistible movement, the Forest Service went into the bunker on that issue.

Another example is very different. In Region 6, the Pacific Northwest, the Forest Service has gone to great lengths to follow the scientific evidence to protect old growth habitat, by using the spotted owl as in indicator species. Tremendous political pressure has been exerted on the agency to alter its proposals. But the agency has shown a great deal of courage at several points in this process, and more often than not, has followed expert scientific conclusions.

Let me finish then by drawing out some very broad directions that the Forest Service might take if I am correct about our already being into the beginning point of an evolution into public use. The Forest Service ought to do two basic things. It ought to consolidate it's authority, and it ought to be a leading advocate for good resource policies when public uses are threatened.

We will learn a lot about the Forest Services willingness to consolidate it's authority, whether it will act as it did with houseboats on the one hand or with hard rock mining recently on the other. And we will learn about it's willingness to act as an advocate within the next few years in regard to a proposed water project that is just about 40 miles southwest of here - the proposed Two-Forks Dam.

Denver and other metropolitan users want to build a 550-foot-high dam and flood some 22 miles of Blue Ribbon Trout Stream in the South Platte River Valley. The draft EIS will be out in a month or two. There are many signs that this is an old-style western water project, perhaps one of the last ones to be proposed--one that is economically and environmentally unsound. The Forest Service staff has worked diligently on Two-Forks in terms of conducting research and analyzing the many issues involved. Two-Forks would be within Roosevelt National Forest and would require the issuance of Forest Service permits. But the question is what the Forest Service will do after the EIS comes out.

The Forest Service for too long has failed to have a water policy, despite its broad occupancy and use authority upheld by the courts. The supposed rationale of the Forest Service of deferring to state water law is bankrupt. The defiance of California, Montana, and Idaho state water pollution laws shows that. The Forest Service ought to bring to an end it's abdication in the area of western water. It ought to participate fully in the making of western water policy in a number of different ways, just as it participates in the making of western timber policy. We will begin to see with Two-Forks whether the Forest Service will take a position as a leader on western water, always and ever the leading resource issue out here.

Top officials also ought to begin developing in earnest, or perhaps continue developing, a program that will deal with agency financing of the National Forests if harvest levels taper off. A good slice of revenues from different development programs go into the Reclamation Fund which will not much be used in the future. Perhaps adjustments should be made there. Mineral leasing programs from National Forests don't go back into the forests. Maybe all or part of those funds ought to go into the agency's budget. Fees need to be explored for all users, including recreational users, seriously. Whatever the specifics, an amended system of revenues needs to be developed now to deal with changing times.

The Forest Service ought to continue its struggle over what is in some ways the ultimate issue for it as an agency, which is to reclaim its historic independence. Over the past 15 years, the Agency has lost control in various contexts - to the Assistant Secretary's Office, to Congress, to the courts, to industry, and to environmental groups. Ironically, the Forest Service has begun to regain independence in some situations by bringing in outside mediators. Mediation has worked in a few situations. When it does, it brings the Agency closer to its public, closer to the mission of fulfilling public needs through consensus. But, in general, authority recently has trickled away caused by and accompanied by, a loss of credibility.

For a substantially independent Forest Service, finding answers mainly from the sciences and from public input has a proven unique potential for good results. Perhaps it is time for a second Pinchott letter.

One thing was probably cemented by yesterday's election. We will not soon return to the excesses of the administration in the area of natural resources policy. I don't say that in a partisan way. I see no basic distinctions between the Nixon, Ford, and Carter administrations in natural resources. But I do see differences between those years and Burford, Crowell, and Watt. Yesterday's results tell me that the next administration of either party will be ready for progressive, future-looking policy initiatives.

The new Assistant Secretary ought to go the the Chief and request the Chief to draft a letter to himself from the Assistant Secretary. The letter ought to set out in ringing terms what it is that the Forest Service stands for, what it is that it as an institution believes in. It ought to be an evocative statement that goes beyond planning, beyond net public benefits, and beyond acting as a referee. It probably ought to speak of public use because that is probably where the future is. This would return authority and independence to the Forest Service.

A strong, independent Forest Service can be the best trustee for these lands, and the Forest Service has always been strongest when it has used the sciences to listen to the commands coming up from the ground and when it has been the champion of the future, not the captive of the past. I hope we soon begin a far-ranging debate on whether public use really is the concept of the future. If it is, I hope that the Forest Service will fully embrace it exactly as a great conservation agency should.

Closing Remarks

FORPLAN: An Evaluation of a Forest Planning Tool -- A Summary

Roger A. Sedjo[1]

Abstract.--FORPLAN has potential to be useful as a decision making tool in public forest management, but this potential has not yet been realized. The model needs to be used for more limited purposes in simpler and smaller forms. Also, FORPLAN should be supplemented with more specific analytical tools which have tactical and on-the-ground applications.

In this "summary" I recount briefly some of the major points raised by the papers of the conference that make up this volume--their similarities and their differences--and then identify the consensus that I perceived as emerging over the three days of the symposium. Some persistent differences will also be noted. While the symposium was designed to focus on the FORPLAN model, the discussion showed that it is often difficult to untangle the model from the planning process, and the planning process from the plan. This summary will range beyond the model, thereby reflecting the nature of the discussion of the symposium. The symposium evaluation of FORPLAN reached much consensus during the three days of the meeting. This paper will focus on that consensus.

Overview

The first one-and-one-half days presented a useful review of the variety of political, legislative, interest group, bureaucratic, technical and other background considerations that influenced the development of FORPLAN and its use in Forest Planning. The relationship of the predecessor models such as Timber RAM and MUSYC and the tendency of FORPLAN to incorporate new types of models into its broad perspective was noted. Also, the role of the Committee of Scientists was discussed. While many of the individual groups and events were familiar to most who attended, a discussion of the role of these events in the development of the FORPLAN model provided a useful backdrop for the remainder of the symposium. Some presentations were used to show the broad applicability of FORPLAN to non-Forest Service users. In the process, the FORPLAN model was described as being a software package which has broad usefulness because of its flexibility for many applications. Examples of its use included applications by industrial firms and applications to Third World countries. We also learned why FORPLAN was not applied to certain regions, for example, British Columbia.

The major focus of the meeting, however, was on assessing the usefulness of the FORPLAN to help in public forest planning in a context such as in the U.S. where multiple-use considerations dominate and the forest is used to produce a variety of outputs, both priced and nonpriced.

Criteria of Success

The discussion of the first one-and-one-half days was descriptive and largely positive. The application of the FORPLAN to the Shoshone National Forest was used as an illustration of the model's ability to help in the development of a plan and in decision making. In the Shoshone, FORPLAN provided input into the decision to move ahead with certain activities that were controversial but sensible. More generally, some of the early presentations characterized Forest Planning, and by inference FORPLAN, as a **success**.

This raised the question of what constitutes a success. Several criteria emerged. Out of the legislative activities that surrounded the Resources Planning Act (RPA) and the National Forest Management Act (NFMA) came two objectives that the legislation was designed to achieve. These were (1) the reduction of conflict, or more broadly what I'll term a political criterion, and (2) the improvement of decision making regarding the national forests. These objectives can be viewed as criteria with which to evaluate the success of forest planning and also by inference the FORPLAN.

Other goals and criteria also might be considered. For example, a former Associate Chief of the Forest Service has cited an important effect of the planning process as that of helping the Forest Service in the budget process. Norman Johnson, in his luncheon address, suggested that the FORPLAN has functioned to protect the Forest Service from its critics by providing a shield of technical jargon with which many critics cannot effectively deal. (This view, however, was vigorously contested.) Similarly, planning may have had the positive effect of forcing the Forest Service to take an integrated view of all of its resources, not just timber, and to force the explicit consideration of economic and biological considerations. Others noted that the FORPLAN has led to staff training and increased technical expertise. While all might not agree that the above outcomes of the FORPLAN and the planning process were among the goals, stated or unstated, these types of effects have occurred, and have resulted in labeling the process as either a success or a failure.

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[1] Senior Fellow and Director, Forest Economics and Policy Program, Resources for the Future, Washington, D.C. Comments presented to the FORPLAN Evaluation Symposium, November 3-5, 1986, Denver, Colorado.

Reduce Political Conflict

Reducing conflict was one of the stated goals of the planning process. How well have we done? Conflict persists, but probably no more (and possibly less) than without planning. The Beuter/Iverson paper seems to see FORPLAN and the planning process as a success largely in political/ conflict terms. Similarly, Binkley's comments suggest that conflict related to the National Forests may have been reduced since the advent of planning. While not eliminating conflict, the planning process may have provided a point upon which the conflict may focus. It may have allowed the conflicts to proceed in a more orderly, less chaotic fashion. It is too early to know whether conflict has been reduced or merely rechanneled or perhaps postponed. While the question still awaits the future for a definitive answer, the preliminary assessment is that conflict has been reduced.

Improved Decision Making

Has forest planning and the FORPLAN model in particular led to improved decision making? If the answer thus far is negative, does it give promise of leading to improved decision making in the future? As noted above, FORPLAN received high marks for its usefulness on some forests, e.g., the Shoshone. However, over the course of this symposium the FORPLAN has also received a host of criticism. A recurring criticism has been that the model, as typically applied in forest planning, is too large. The criticisms of large models are of two types, general and technical. The general criticisms include:

1. the models as developed are beyond the capability of most of the staffs;
2. the models tend to dominate the intellectual effort of the staffs and, therefore, preclude use for analysis and stifle creativity;
3. the FORPLAN exercise tends to dominate, becoming the plan rather than the tool;
4. FORPLAN often is used to justify site specific actions beyond its design or capability.

In summary, the criticism was that in trying to be comprehensive and include everything, the model lost its ability to be a useful, flexible and perceptive analytical tool.

Other specific criticisms included that of the Beuter/Iverson paper, in which they stated that they did not know if it improved decision making, and Binkely's paper where he contrasted seven costs (unweighted) of the FORPLAN with only two benefits. Another often-expressed concern was the lack of a budget in the planning process. The absence of a budget to give a scale of the relevant range of a plan could lead to serious errors in the mix and level of planned forest outputs.

Several specific technical criticisms also were directed at the model. These included technical problems related to its size, problems related to linearity, lack of validation, data problems--especially when dealing with data with large but unknown variance, etc.

Toward Improving FORPLAN

Despite the criticism, there was also considerable support for the FORPLAN model, in concept, as an analytical tool. There seemed to be general agreement that:

1. FORPLAN could be useful as a "strategic" model to provide a broad overview.
2. The model should be kept small and of minimum complexity.
3. Other tools and models ought to be used at the tactical and implementation levels to complement and supplement FORPLAN.

The model should be kept small, manageable, transparent and understandable. In essence, the "white box" approach is preferred in which the projections are either intuitive or, if not, the counterintuitive results can adequately be explained be tracing through the model. Currently, FORPLAN is typically a "black box," the output of which often cannot be explained and therefore must be accepted on faith. When dealing with counterintuitive results, the decision maker has no way of knowing whether the result is an artifact of the model or if it represents a complex but sensible reality. In this context, a good decision maker would tend to discount or wholly ignore such counterintuitive results. Such a response seriously reduces the model's value as an analytical tool.

Conclusions

While FORPLAN has potential to be very useful as a decision making tool in public forest management, this potential has not yet been realized because of the model's tendency to be overly large and comprehensive. To be useful the model needs to be used for more limited purposes in more simple and smaller forms. In addition, the FORPLAN tool should be supplemented with a variety of more specific analytical tools that have tactical and on-the-ground applications.

Concluding Remarks and Symposium Summary

John Sessions[1]

Abstract.--The major points of discussion are summarized in terms of FORPLAN's ability to (1) improve the planning process, (2) improve communication, and (3) improve decision making. There was general agreement that FORPLAN met the analytical requirements of the National Forest Management Act. The sharpest criticism was the inability to model nonlinear relationships and operational difficulties with large models. Several variations of hierarchical planning were suggested. Additional analysis beyond the forest-wide FORPLAN analysis appears to be needed.

The objective of this symposium wasto document and evaluate the implementation of FORPLAN. I will not attempt to summarize each speaker's paper as this has been excellently done by the various discussants and my co-panel member, Rodger Sedgo. I will try to identify the major areas in which the speakers and audience participants agreed or disagreed and suggest where we might go from here.

Using the framework suggested by John Beuter, we can evaluate the success that FORPLAN has had in (1) improving the planning process, (2) improving communication, and (3) improving decision making.

Concerning improving the planning process, there was general agreement that FORPLAN met the analytical requirements of the National Forest Management Act (NFMA). Teeguarden suggested that some type of mathematical tool would have been required to meet the analytical requirements of NFMA. Wilkinson commented that the level of analysis in FORPLAN exceeded the requirements of NFMA.

There was general agreement that certain issues needed to be dealt with outside of the model. Teeguarden rated the ability of FORPLAN to achieve the planning requirements into 16 categories and concluded that the weakest categories were in linkages to issues outside of the forest such as the demand curves facing the forest which involved regional linkages and regional cumulative effects. Shugart agreed that FORPLAN adequately could represent the ecological linkages if adequate estimates of the yield coefficients were provided using small scale ecological models and large scale ecological models used to verify the total FORPLAN "solution." All speakers recognized the limited ability of a linear programming model such as FORPLAN to model spatial relationships but agreed that it was not a fatal flaw that could not be achieved by some form of later analysis outside of FORPLAN. There were some concerns among participants, however, about how watershed, recreation and mineral resources were being addressed within FORPLAN and these questions went unanswered.

There was considerable discussion about whether FORPLAN improved communication. Communication takes place at three levels; within the planning team, between the planning team and the Forest Supervisor, and between the Forest Service and public. There was general agreement that FORPLAN could enhance communication between the planning team and the Forest Supervisor, but the Forest Supervisor would need to remain in close contact with the team to understand the complex modeling relationships, implicit and explicit assumptions.

Within the planning team, FORPLAN provided a common framework for specialists to communicate and to see that their concerns were integrated into the plan. There was disagreement about whether communication between the public and Forest Service was improved using FORPLAN. It was suggested that because of its complexity FORPLAN might be used as a shield between the Forest Service and the public to justify agency positions. Others, such as Binkley, reasoned that the standard approach to analysis provided by FORPLAN increased the ability of large centralized interest groups to follow the analysis more easily after some initial investment in model study. Mealy cited examples where the public participation increased with the ability of the public to work together with the planning team in putting together prescriptions and seeing the total results in a forest context.

There was general agreement that FORPLAN was not the Forest Plan, but a tool to aid decision making. Daniels and Mealy felt that FORPLAN aided decision making. Davis proposed using FORPLAN in a "with" and "without" application to measure the improvement in decisions. He suggested doing this on a smaller scale in industrial applications. Greg Jones, using the Integrated Resource Planning Model (IRPM), recently completed a similar experiment to measure the efficiency of alternative planning methods in the northern Rocky Mountains. Jones found large increases in efficiency could be gained when spatial relationships were important.

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[1] College of Forestry, Oregon State University, Corvallis.

The sharpest criticism of FORPLAN came from the operations research panelists including Bare, Fields, Dykstra, and Navon. The operations research group agreed that the major shortcomings in FORPLAN were the same as in any large linear programming model. These limitations were assumptions of linearity in modeling reality, the difficulty of identifying measurement errors, and the cost of running the very large models. All four operations researchers proposed a hierarchical approach to forest planning to reduce model complexity and increase the ability to analyze the problems specific to that level of planning.

There was agreement that one or more additional levels of analysis would be needed besides a forest-wide application of FORPLAN. These added levels of analysis might take place above and below the forest level to meet specific needs. At a higher level, analyses might establish guidelines for FORPLAN-forest applications. This has been proposed before in terms of a regional plan.

At a lower level, more site-specific planning could be done to insure the plans are implementable and to provide detailed information for short-term budgeting. This need for a tactical plan is becoming more widely recognized throughout the Forest Service and is being termed "area analysis."

I concur with the previous speakers' concerns about hierarchical planning. FORPLAN must be considered a strategic planning model. Many of the current problems facing public forestry cannot effectively be dealt with by strategic planning models. Problems that require spatial, site-specific analysis can only be cursorily considered in forest-wide planning models. Typical issues include "sales below cost" and "cumulative effects".

It seems that the focus will shift from strategic planning which concentrates on estimating average effects over the forest for the long term (100-200 years) to tactical forest planning that concentrates on estimating site-specific effects for logical geographic areas for the short term (5-50 years).

This tactical planning involves a comprehensive, in-depth analysis of the projects that should be selected for an area over the next few years or decades given certain objectives and constraints. Spatial analysis, estimation of site-specific effects and detailed consideration of logging and transportation choices are important facets of this approach.

Very little research, development, training and extension is being conducted on tactical forest planning. Much of the recent research and development has centered with the Management Sciences Staff under the direction of Mal Kirby. One notable output has been the Integrated Resource Planning Model. Work on increasing the efficiency of this model is being done by Greg Jones at the Intermountain Station. Outside the Forest Service, universities occasionally have projects that touch on tactical forest planning, including Teeguarden's work on the economical suitability of timberland and my own work on designing road systems to efficiently access a specified set of cutting units.

Johnson and I have previously proposed research on tactical forest planning to the Forest Service. The needed work in tactical forest planning includes:

(a) What questions a tactical planning model should answer.

(b) An evaluation of the ability of existing models, such as IRPM and FORPLAN (Version 2), to answer these questions.

(c) Design changes in these models to make them effective in tactical forest planning, or design new models to do these tasks.

(d) Development and evaluation of different types of linkages between these planning models and geographic information systems.

(e) Design changes in tactical planning models and geographic information systems to make a smoother and more informative linkage.

(f) Development and evaluation of different types of linkages between strategic and tactical planning.

(g) Analysis of different policies that can be applied in tactical planning, such as constraints on maximum clearcut size, or a requirement that all sales or groups of sales must pay for themselves, in proportion to their economic and environmental effects.

In closing, I must conclude there is general agreement that FORPLAN has made a significant contribution to forest planning. The economists, the ecologists, and the managers here have largely been satisfied by the ability of FORPLAN to adequately represent their concerns and address issues at the forest level. Over the last several days I have played the devil's advocate to draw out criticisms of FORPLAN and the criticism is surprisingly mild. Perhaps we are exhausted after 10 years of planning?

Thank you for this opportunity to participate.

U.S. Department of Agriculture
Forest Service

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